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Geology for High Schools

M. B. B. CROCKFORD, M.Sc., R.P.E.

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Geology for High Schools

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SECOND EDITION

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EDMONTON — ALBERTA

PREFACE

* * * *

This manual is an attempt to supply the needs of students and teachers of Geology in the High Schools of Alberta. The course in physical geology prescribes that the geological and geographical features of our own province should receive particular attention. It is widely felt, however, that in class-room practice these considerations are not getting due emphasis. The reasons are easily explained: Students are bewildered with the number of scientific works recommended, and they do not know which are most fruitful to consult in order to obtain the desired information. Besides many of the geological reports and texts are highly technical, and others again are not procurable. This manual has attempted to remove these difficulties by providing at the end of each chapter a list of source-books of more detailed information, by giving as far as possible explanations in non-technical language, and by taking, wherever practical, examples from Alberta.

Diagrams and photographs have been carefully selected to illustrate the important geological features, for next best to viewing the real thing is a photograph or diagram of it. Wherever possible illustrations from our province have been used.

The outline in the course of studies has been rigidly followed with amplification here and there for the purpose of added interest and clarity. Field and laboratory work should accompany study of the reading matter. Collection of minerals, rocks and fossils, snapshots and pictures of geological interest, studies of local rock formations, examples of erosion, weathering and deposition—these are some of the projects that can be carried on in conjuction with the regular lessons.

It is believed that these studies and researches will give students a better understanding and appreciation of the natural phenomena of their surroundings. This understanding and appreciation can be attained only by a thorough knowledge of the constructive and destructive forces of nature which are at work everywhere shaping and reshaping the contours of the earth's surface. Every hill, valley, plain or other geological feature should suggest to the student the question of its origin, the forces that built it and the forces that are destroying it. The solution of these problems is nearly always evident to the trained observer. But the training necessary to make these solutions comes only with practice. As in other sciences, careful observation and open-minded inference are indispensable to progress. Those who intend to follow some branch of geology as a profession will get in these pages a useful introduction to the subject; but even the casual student should acquire the fundamentals of geology which will add interest to the out-of-doors.

The writer is greatly obliged to Dr. J. A. Allan, head of the Department of Geology, University of Alberta, and expresses herewith his sincere appreciation of the many valuable suggestions regarding arrangement and material which followed his reading of the original manuscript. Dr. Allan's many years of experience in the practice and teaching of Geology make his contribution no mean one. In addition he has permitted the reproduction of many photographs of his, these being Figures 1, 6, 7, 30, 33, 35, 36, 37, 38, 42, 43, 46, 52, 59, 76, 77, 85, 89, 99, 103, 104. To Dr. P. S. Warren and Dr. R. L. Rutherford of the Department of Geology, University of Alberta, and Professor E. Stansfield of the Research Council of Alberta, many thanks are given for reading and criticizing parts of the text. Mr. W. A. Thorn of the Dominion Meteorological Service, Victoria, kindly contributed certain information and pictures respecting seismographs. By permission of D. C. Heath and Co., New York, the following Figures from "Text Book of Geology" by A. W. Grabeau have been used in this work: Figures 2, 4, 21, 22, 23, 24, 25, 26, 29, 41, 44, 45, 48, 49, 51, 54, 56, 57, 58, 60, 65, 66, 67, 68, 69, 70, 74, 75, 80, 83, 84, 88, 90, 91. The writer is greatly indebted to these publishers for the privilege granted him to use these illustrations. The writer assumes responsibility for all statements contained in this book.

Geological reports and maps for any particular area can be obtained on application to the Geological Survey of Canada, Geological Division of the Research Council of Alberta, and the United States Geological Survey. A useful map to have is "Geological Map, Alberta" (1937), by Dr. J. A. Allan, University of Alberta.

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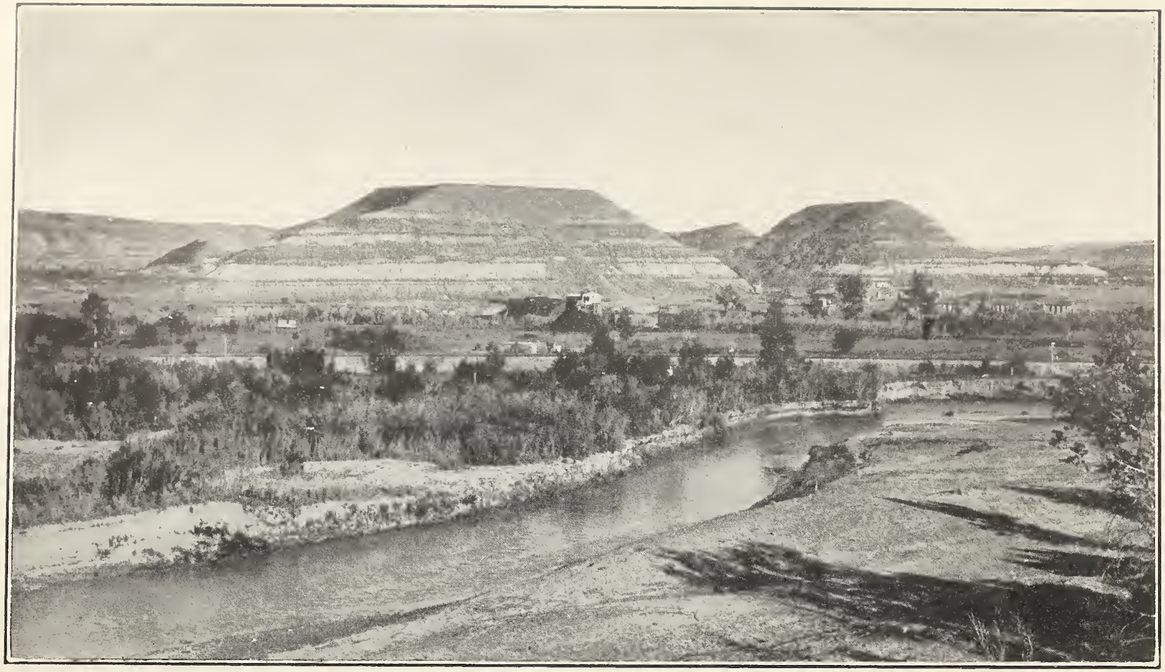


FIG. 1

Typical buttes in the Drumheller area along Red Deer River near the mouth of Rosebud River, showing a bed of white bentonitic sandstone; note the horizontality of the strata, which belong to the Edmonton formation.

CHAPTER 1

* * *

SOME GEOLOGICAL FEATURES OF THE EARTH

1. **Branches of Geology.**—Broadly speaking, geology is the science of the earth and all that relates to it, and would embrace such subjects as Meteorology, Geography and Oceanography. Traditionally, however, geology is restricted to the study of the earth's crust or lithosphere. It is in the latter sense that the term is used in this work.

Geology is made up of a number of separate sciences, all more or less related. Some of these are: **Mineralogy,** the study of the minerals of which the earth's crust is composed; **Petrology,** the study of the rocks of the lithosphere; **Paeleontology,** the study of the life of the past as recorded in the rocks by fossils; **Stratigraphy,** the study of the rock strata and their mode and order of development; **Economic Geology,** the study of mineral deposits such as copper, coal, oil, etc.; **Seismology,** the study of earthquakes; **Volcanology,** the study of volcanoes; and **Physical Geography,** the study of surface forms of the earth's crust resulting from destructive forces such as rain, running water, glaciers, wind and waves, and such constructive forces as crustal movements, earthquakes and volcanic action. **Physical Geology** is a derivative of physical geography but has a wider scope.

2. **Our Earth's Origin.**—How the solar system originated has long been a subject of speculation and many explanations have been offered. The best known of these are: The Nebular Theory, the Planetesimal Hypothesis, and the so-called Stellar Theory. Each of these meets with serious objections, so that no one of them is universally accepted. They agree, however, on one basic dogma, viz., all members of the solar system have resulted from the collection and condensation of gases and other matter about certain nuclei.

The Nebular Theory assumes in the beginning a **nebula** (a mass of hot rarified gases) in the form of a flat plate having the radius of the distance from the sun to the outermost planet, Pluto—a distance of about 3,675,000,000 miles. The nebula was rotating and cooling, and as it cooled the matter at its outer edge contracted and collected about a nucleus. This matter separated from the main body of gas and on further cooling formed a planet. In like manner other planets originated, and as cooling progressed the whole nebula broke up into separate masses. Pluto was the first to form, and then in order Neptune, Uranus, Saturn, Jupiter, the Asteroids, Mars, Earth, Venus, and Mercury, the nearest planet to the sun. The masses of gas may in turn have given off other bodies of gas. These on cooling formed the moons which revolve about some of the planets. The masses of gas cooled to form first liquid spheres, and when sufficiently cooled these developed crusts of solid rock. Water vapor condensed and collected in basins to form the oceans. The sun is the hot central mass which remained after the planets had split off.

The Planetesimal Hypothesis supposes a spiral nebula with arms containing many planetesimals. (A planetesimal is a small heavenly body which wanders around in space and may become a shooting star on entering the earth's atmosphere.) The planetesimals collected about certain centers as they were drawn together by their gravitation. As they collected they became heated. Accretion of these heavenly bodies formed the planets, some of which grew to a great size, much bigger than the earth. They were quite hot at one time but are now losing heat. The center of the spiral nebula is now the sun. According to this theory the moons were never part of the planets but were separate nuclei which never attained any great size.

Some astronomers favor the Stellar Theory, which places the origin of the planets in the sun. At some remote time, hundreds of millions of years ago, they suggest a star passed close enough to the sun to cause a tide in it, and to draw out from it a long cigar-shaped mass of gas. As the star passed on, this huge body of hot matter was pulled completely away from the sun and left suspended in space. It quickly cooled, the gases collected about centers, and in time the planets grew out of them. Support to this explanation is given by the fact that the size of the planets increases from Mercury to Jupiter, as the distance from the sun increases, and then decreases until Pluto is reached.

3. **The Age of the Earth.**—The earth is very, very old, for the oldest rocks known to geologists were laid down on its surface some 1,700,000,000 years ago. It must be assumed then that the earth had its beginning long before that time. Several methods have been used to calculate the age of the earth. In each case the figures arrived at can be claimed as only rough estimates.

One of these methods uses the amount of salt in the ocean. As this amount has been deposited year by year by streams and rivers, the total amount divided by the annual contribution gives the approximate age of the earth. This method, however, is not considered accurate, as the land area of the earth from which the salts are derived has varied in the past and the amount of salts carried each year to the ocean has varied accordingly. Another way is based on the rate of accumulation of sedimentary rocks (limestone, sandstone, shale, etc.), and the total thickness of such deposits; but this meets with the difficulty that unknown thicknesses of these sediments have been removed by erosion, and the estimate is too small.

The most accurate method of measurement involves radio-activity. It is known that the heavier minerals such as uranium and radium slowly disintegrate, passing through successive stages and finishing up as lead. The rate of change from uranium to lead is constant under all conditions of heat and pressure and thus the relative amounts of lead and uranium in rock can be used to calculate the age of the rock. By this method the age of the earth has been calculated to be about 3,000,000,000 years.

4. **The Spheres or Shells of the Earth.**—The earth consists of three familiar components; viz., the **Atmosphere,** the **Lithosphere** and the **Hydrosphere,** and a fourth part, the **Centrosphere** (Fig. 39). The lithosphere or earth's crust is the solid rocky part on the surface of which we live. It is many miles thick, perhaps 65 or more, and the study of it is Geology. The hydrosphere is the liquid envelope which partially surrounds the lithosphere and includes all the oceans, seas, lakes, etc. The study of the oceans, **Oceanography,** is a science separate from geology. The outer gaseous envelope surrounding the solid and liquid spheres is the atmosphere, and the study of it is known as **Meteorology.** The centrosphere is that part which forms the central core of the earth and lies inside the lithosphere. As it lies too deep to be accessible to man, what is known about it has been learned by studying earthquake waves or has been drawn by inference.

5. **Movements of the Earth's Crust.**—Through the agencies of weathering and erosion the earth's surface is undergoing continual change. Mountains and hills are being worn down, valleys are being widened and deepened, lakes are being destroyed, and by pounding of waves the sea is cutting into the land and reducing its surface area. Accompanying these changes there are movements of the lithosphere, which may alter still further the "face of the earth" by creating new mountains and plains or by causing such features to sink beneath the sea. Thus the shorelines as well as the profiles of the land are ever changing; some of these changes occur rapidly (in a few seconds or, at most, in a few hours or days), but in most cases they come about very slowly.

Elevation and depression of the earth's crust produces high lands (lands above the sea) and troughs, which may be occupied by seas or other bodies of water. Materials such as gravel, sand, clay and soluble salts may be eroded from the high lands and deposited in the basins, where in time they form beds of sedimentary rock.

(a) **Slow Movements of the Earth's Crust.**—As a rule these earth movements take place so slowly that the changes that they effect may not be noticeable in one man's lifetime, and the observations of centuries are necessary to ascertain their extent. Measurements made in northern Sweden indicate that that region has been uplifted seven feet in the last 150 years. In Scotland sea beaches are found 25, 50 and 100 feet above the level of the sea—clear testimony that either the land has risen or the sea lowered. At Pozzuoli, near Naples, Italy, exist the ruins of a temple built over two thousand years ago. Since that time part of the temple has been below sea level, for its marble columns have been perforated by marine animals to a

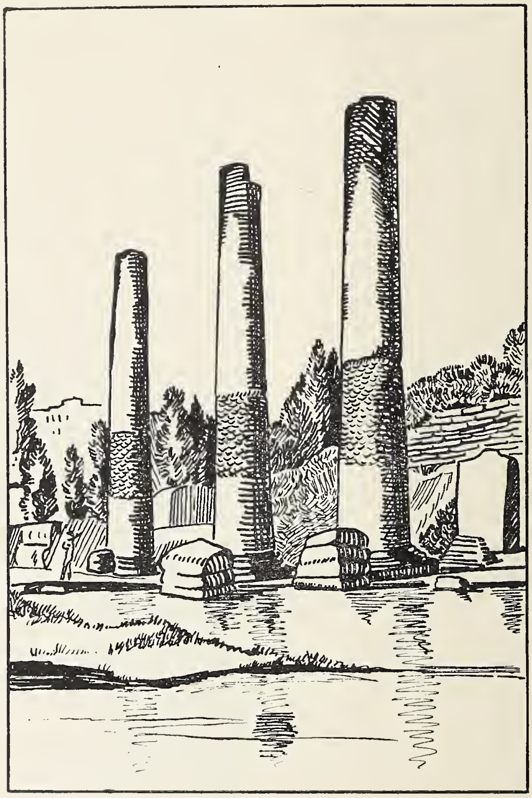


FIG. 2

Ruins of the temple of Jupiter Serapis in 1840 at Pozzuoli, Italy, on the bay of Naples; the borings of marine animals to a height of over twenty feet can be seen on the limestone columns—evidence that at one time these pillars must have been below the sea to that depth.

height of 23 feet. The floor of the temple is now a little above sea level (Fig. 2). The basins of the Great Lakes are being tilted to the south by the rising of the land to the north. One authority has estimated that the level of Lake Michigan at Chicago is rising at the rate of nine inches a century, and that drainage of the Lakes in 3,000 years will be by way of Chicago to the Mississippi.

(b) **Rapid Movements of the Earth's Crust.**—Rapid movements of the earth's crust have been recorded in the past few years. New Zealand has had many earthquakes; one of these, in 1855, raised a portion of North Island nine feet, and the raised part could be traced for ninety miles. In 1899 at Yakutat Bay, Alaska, the coast was uplifted by an earthquake in some places as much as forty feet. In other places it sank below sea level. Mussels and barnacles attached to rocks gave evidence of elevation of the land, and trees dying in salt water furnished proof of subsidence. A great wave or "tsunami," produced by this earthquake, destroyed a forest forty feet above the level of the bay. In the California earthquake of 1906 horizontal movements accompanied the usual vertical ones. Fences and roads were displaced sideways so that the broken ends were in some cases as much as ten feet apart. Vertical shifts gave rise to fissures. Much of the destruction in the city of San Francisco was caused by fires which could not be extinguished on account of the severing of the water pipes by the shocks.

(c) **Prehistoric Movements.**—The foregoing movements have taken place in the history of man, but there is every reason for believing that similar movements have been taking place throughout the whole history of the earth. Some of these movements have had a vertical displacement of thousands of feet. The remains of corals, shellfish and other marine animals commonly found in the rocks of many mountains, clearly prove that those rocks were once sea bottom (probably part of a continental shelf or bottom of an arm of the sea) (Fig. 3). The Rocky Mountains in Alberta yield marine fossils in most places. Some have been found on the peak of Mt. Robson, 12,972 feet above sea level. In the Himalaya Mountains marine fossils have been found as high as 16,000 feet above sea level. Sharks' teeth are found in the bad lands of Red Deer and South Saskatchewan Rivers. The remains of other marine animals are plentiful in many parts of the province where bed rock is exposed. All these illustrations indicate changes in the level of sea and land, but whether it was the land that rose or the sea that sank has not been determined in all cases.

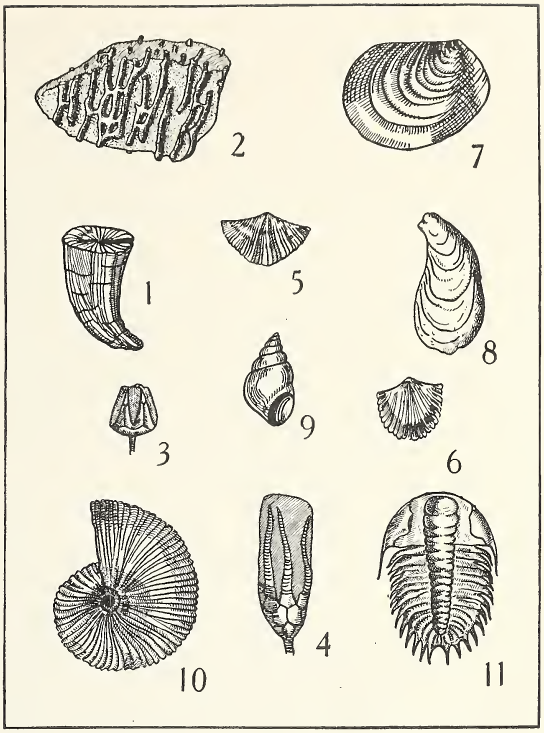


FIG. 3

REPRESENTATIVE FOSSILS OF MARINE ANIMALS

1. A cup coral from the Rundle formation, Lake Minnewanka.
2. Rock containing coral, colonial (branching) form, from the Rundle limestone, Banff.
3. A blastoid of Mississippian age from the Mississippi valley.
4. A crinoid from the Ordovician of Ontario.
5. A brachiopod from the Beaverfoot formation (Ordovician), Palliser Pass, southern British Columbia.
6. A brachiopod from the Rocky Mountain quartzite, Banff.
7. A clam (pelecypod) of a type common in the Bearpaw formation in the southern parts of Saskatchewan and Alberta.
8. An oyster (pelecypod) from the Belly River formation; collected near Taber.
9. A snail (gastropod) from the Belly River formation near the junction of Bow and South Saskatchewan Rivers.
10. An ammonite from the Bearpaw formation in southern Saskatchewan.
11. A trilobite from the Stephen shale on Mount Stephen, Field.

(All fossils shown one-half natural size)

(d) **Causes of Change in Sea Level.**—The following geological activities are the chief factors that determine the level of the ocean: (1) Deepening of ocean basins; (2) Depositing of sediment and volcanic material in the ocean; (3) Emission of water vapor by volcanoes; (4) Acquisition of great volumes of water by glaciers; (5) Union of water with rock in the process of weathering.

(e) **Causes of Change in Land Level.**—On the other hand changes in the level of the land may be explained by: (1) Slow subsidence or elevation; (2) Contraction theory. The contraction theory assumes a molten world at one time, which, as it cooled, developed a hard outer shell. Further cooling and contracting made this outer shell too large for the shrinking interior, so that it became wrinkled, just as the skin of an apple develops wrinkles as the inside flesh shrinks. The wrinkles of the earth's surface are the mountains, plateaus and some hills and ridges. Between the wrinkles are valleys, and lake and ocean basins.

When subsidence occurs there must be a corresponding elevation of the earth's surface to keep the earth evenly balanced. Many thousands of feet of sediment are constantly being transferred from one place on the earth's surface to another, and this accumulation should cause the earth to become heavier on that side. As a result the earth should wobble as it rotated. But as the earth revolves smoothly on its axis some compensation has been made for the removal of rock waste in one place and its deposition in another. This is accomplished by a flow of rock 65 to 75 miles below the surface. The rock situated below the region where the sediment is being deposited flows to the region below that from which the sediment has been carried. As a consequence the earth is always in a state of equilibrium, for denudation is accompanied by elevation of the land and deposition is accompanied by subsidence. This process is as active now as it has been in the past.

6. **Folding and Faulting.**—In the adjustments that take place in the earth (due either to contraction or maintenance of equilibrium) strata are tilted at various angles by pressure from below or from the sides. The angle at which the strata are inclined is called the **dip** (Fig. 4). It is measured from the horizontal; therefore the dip of strata lying perfectly flat is 0 degrees, and that of strata inclined vertically is 90 degrees. The angle in each case is taken by measuring the steepest slope of the stratum. A line at right angles to the dip is known as the **strike**; it will always be horizontal. Dip and strike are measured where the bed rock outcrops, that is, where it is exposed at the surface of the earth (Figs. 6, 7, 33).

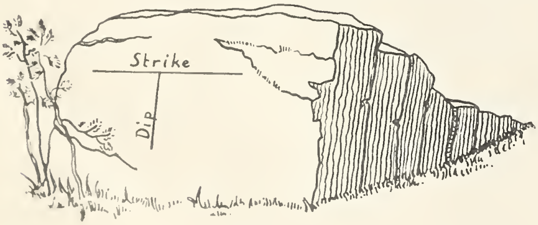


FIG. 4

Sketch of a rock outcrop to illustrate dip and strike; dip is the greatest inclination of the strata as measured along a bedding plane, and strike is a horizontal line at right angles to it.

Tremendous pressure acting on the rocks has thrown them into series of arches and troughs; the arches are called **anticlines** (Figs. 5, 6, 7), and the troughs **synclines** (Figs. 5, 6, 7). In an anticline the strata dip away from a line, the axis; in a syncline they dip toward a line or axis.

Sometimes the rocks have yielded to pressure by fracturing instead of bending, that is, they have faulted, and the break is called a fault. Further pressure may cause the strata on one side of the fault to be shifted with respect to the other block of strata. The fractured surface along which the rocks moved is the **fault plane.** The shift or displacement of the strata may vary from a fraction of an inch to several miles. Faults are of two main types: (1) **reverse** or thrust; (2) **normal** or gravity.

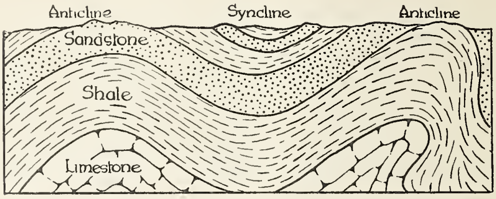


FIG. 5

Eroded anticlines and synclines; anticline on left is symmetrical, i.e., both limbs drop at the same angle; the anticline on the right is asymmetrical.

In a reverse or thrust fault pressure has caused one block partly to over-ride the other (Figs. 8, 79, 102), and older strata are thrust over younger with the result that the total length of the strata has been diminished. The horizontal displacement in this type of fault is as much as 15 miles in the Front Range of the Rocky Mountains of Montana and the Waterton area of Alberta. The strata in a normal fault have been pulled apart, and the total length of the strata has been increased (Fig. 9). The amount and direction of movement of the faulted strata are determined by reference to some recognizable stratum—known as a **key bed.** The key bed may be distinguished by its color, composition, contained fossils or some other feature. A coal seam makes an excellent key bed.

(**Note:** Arrows along fault planes in the figures indicate the relative movements of the blocks of strata).

Sometimes whole blocks of strata have been dropped giving rise to **rift valleys,** one of which is now occupied by Lake Tanganyika, Africa (Fig. 58).

7. **Geological Time Table.**—It is a great convenience to have our time divided into years, days, hours, etc., and so, too, it is convenient to have the past history of the earth divided into

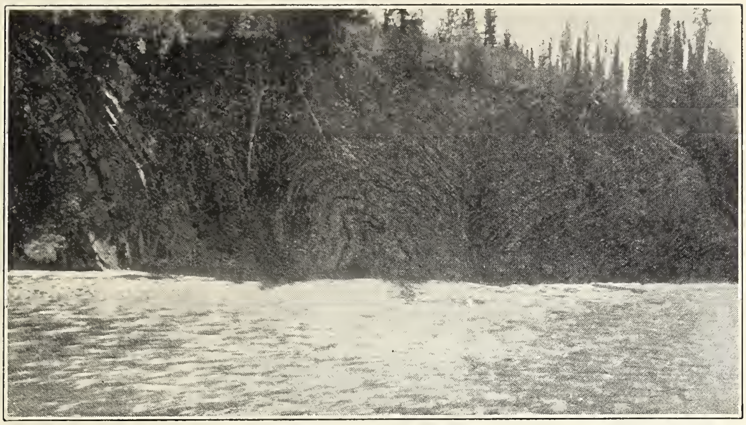


FIG. 6
Folded and faulted beds of Colorado age on Blackstone River northwest of Nordegg.

time intervals. But these time intervals are so great that our time units are not ordinarily used. Just as historical events in many countries are generally referred to in relation to other events such as the reigns of sovereigns, important social reforms, economic events, wars, etc., so is the history of the earth divided into time intervals marked by important events such as the rise of certain kinds of animals and plants, invasions of the sea over the land, elevation of land masses, raising of mountains, etc. The geological history of the earth is divided into four big time intervals called **eras;** viz., Precambrian, Palaeozoic, Mesozoic, and Cenozoic. These are based chiefly on the forms of life which were dominant at the time. Palaeozoic refers to old forms of life, Mesozoic to middle or intermediate types, and Cenozoic to modern forms. In the Precambrian era there is little evidence of much life. The rocks which were laid down in an era are called a **group,** and so we have the Palaeozoic group, etc. Each of the four eras is divided into **periods** which are marked by less important events such as land uplifts, minor mountain-building movements, etc. The rocks laid down in a period are a **system.** The Cambrian system, for example, refers to all rocks laid down during that period. Smaller time divisions are **epoch** and **age** and the corresponding strata are **series** and **formation.** Each of the systems, series and formations is given a name, which in many cases is that of the place where those particular rocks were typically developed or first described. The same formation or series may have been named differently in other localities, either because, when it was described, it was not recognized as being the same as another, or because it varied from it. The Edmonton formation is equivalent to the St. Mary formation of the Lethbridge region; the Colorado shale of eastern Alberta is the same as the Alberta (or Benton) shales of the foothills. (Fig. 6, 7).

The rocks in a formation have a fairly uniform character, a fact which points to similar conditions of deposition of all the strata. The Bearpaw formation in Alberta (named from the Bearpaw Mountains of Montana where the formation is typically exposed) is about 700 feet thick in some places and consists almost entirely of gray marine shale (Fig. 35). It therefore represents an invasion of the sea during the Bearpaw age. In other words, that part of Western Canada we now know as Alberta was at that time beneath the sea. Lying under the Bearpaw is the Belly River formation (sometimes called series), consisting of some 1,500 feet of sandstone and shale with coal seams. These features indicate that that part of the land mass was then near sea level. Above the Bearpaw

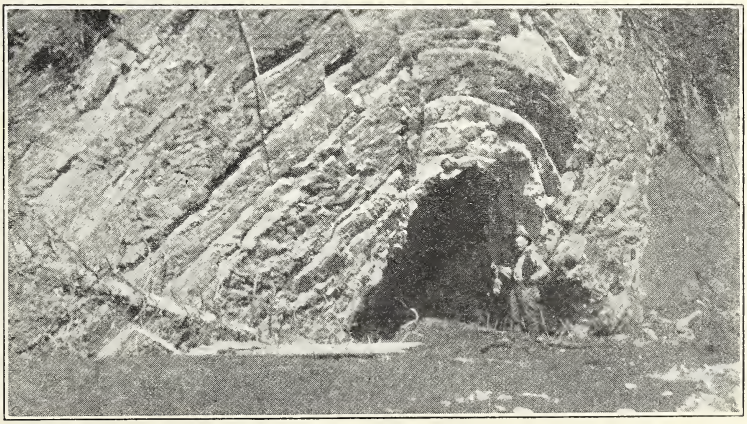


FIG. 7
Anticline and syncline in a sandstone member of the Colorado shale on Blackstone River northwest of Nordegg.

formation is the Edmonton formation, about 1,500 feet thick (Fig. 33). It is similar in origin to the Belly River formation but differs slightly in the composition of the rock. Thus these different formations represent different elevations of the land and different conditions of deposition. Besides the fact that the strata of similar formations are alike, the fossils found in these strata possess the same distinctive characteristics as fossils found in other strata of the same age.

The time required to lay down a rock formation is very great. It has been estimated that 500 years is required to lay down one foot of sandstone. The time needed to lay down one foot of shale is about 800 years, and about 1,500 years are required for one foot of limestone to form. Thus the Belly River age, during which shale and sandstone were laid down in Alberta, could easily be about 1,000,000 years long. These figures are only approximations, for conditions of deposition and erosion have varied widely from time to time.

The rocks of different formations, series, etc., are distinguished in various ways. One common method is by observing the fossil content of the rocks. Fossils (Fig. 3) are the remains of animals and plants which have been preserved in the rocks. If the same species of fossils are found in different localities it is a good indication that the enclosing rocks were laid down about the same time. Not all fossils can be used for this purpose, but some called **index fossils** can be employed to tell the age of the enclosing rock. They can be compared to the figures on the face of a clock, for they indicate a certain time in the past history of the earth. Another way by which rock formations can be correlated is by observing their position, e.g., they may underlie the same known formation. Care must be exercised in using this method, for the rocks may be overturned, in which case younger beds, which are used as a key formation would be below the others. Mineral composition is used a great deal to distinguish rocks. The formation may be of chalk, or contain many coal seams, or be of the same kind of shale, sandstone, limestone, etc., as the known formations; by such identifications it may be correlated with them. Sometimes it is possible to trace the formation from place to place and identify it in that manner. Formations make up series, series make up systems, and systems groups. The kind of rocks in a formation along with the contained fossils (if any) give an index to a certain extent of the conditions of deposition. Sandstone indicates river, beach, or perhaps wind deposits; shale with marine fossils will have been deposited off shore in seas; and limestone is indicative of warm, quiet and undisturbed sea waters of a continental shelf. Thus alternating strata of sandstone, limestone, shale, etc., mean that that place has fluctuated greatly in elevation from below sea level to perhaps many thousands of feet above it (Figs. 23, 24).

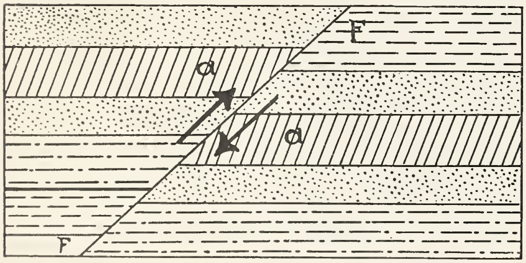


FIG. 8

Reverse or thrust fault; arrows indicate the relative direction of movement of the fault blocks; FF fault plane, aa key bed.

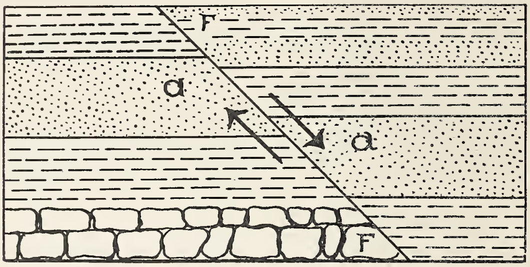


FIG. 9

Normal fault; arrows indicate the relative direction of movement of the faulted strata; FF fault plane, aa key bed.

A word of caution should be given with respect to Estimated Time in the Geological Time Table for Alberta (Fig. 10). These figures are only approximations, for authorities differ greatly in their estimates of the age of the earth. However, whatever total age of the earth be taken, the ratios between the length of the various eras, periods, etc., are about the same.

Questions:

As there are too many questions for the student to do in one year, the teacher will select those which are of the greatest value or interest.

1. Define geology.
2. (a) What is a nebula?
   (b) According to the Nebular Hypothesis how was the Solar System derived from a nebula?
3. (a) What is a planetesimal? Are there any still left in space?
   (b) How might the Solar System have originated from such bodies?

4. (a) Explain briefly the Stellar Hypothesis which tries to explain the origin of the Solar System.
   (b) What support is lent to this hypothesis?
5. (a) What is the age of the oldest rocks of the earth?
   (b) Outline briefly the method of calculating the age of the earth by using the amount of salt in the ocean.
   (c) What is the chief objection to this method?
   (d) How can the thickness of the rocks be used to determine the age of the earth? Does this method give accurate results? Explain.
   (e) How is radio-activity used to determine the age of the earth?
6. Name the four spheres or shells of the earth and the science which deals with each.
7. (a) Distinguish between rapid and slow movements of the earth's crust.
   (b) Give one example of each kind of movement.
   (c) What conclusive evidence have we that Alberta has been sea bottom in times past? Give two examples.
8. (a) Name three factors which may cause sea level to sink.
   (b) What two things might cause the level of the sea to rise?
   (c) By means of the contraction hypothesis explain the changes that occur in land level.
   (d) How does rock flowage maintain the equilibrium of the earth? Why is it necessary?
9. (a) Define: dip, strike. Illustrate by a diagram.
   (b) Draw a diagram of each, and describe: anticline, syncline.
   (c) Draw a diagram of a normal fault; of a thrust or reverse fault. How is each produced?
   (d) What is the use of a key bed?
10. (a) Learn the different eras, periods, and epochs in the Geological Time Table.
   (b) Give three ways by which a rock formation might be identified.
   (c) A rock formation is composed of 400 feet of limestone and 150 feet of shale. How long was required for the rock to form?
   (d) How long a time interval is represented by 1,000 feet of sandstone and 500 feet of shale?
   (e) Colour in the following figures, using a different colour for each formation: 5, 8, 9, 31, 32, 35, 40, 70, 78, 79, 98, 100, 102.

Suggested Activities:

1. Many fine pictures which will interest the student of the geology of Alberta are to be found in snapshots and illustrations from pamphlets, magazines, and newspapers. These geological features are given considerable publicity, for Alberta's plains, foothills, and rugged mountains abound in natural phenomena which attract the tourist and student. Therefore many examples of geological processes are found in this province, and it does not take long to make a collection of pictures of them for use in the classroom. If there are no facilities for projecting these pictures onto a screen, then they might be passed from student to student. In order to prevent soiling during handling place the picture between two glass plates, which are fastened together with rubber bands. These glass plates may be easily cut to the approximate size from old window glass; moreover their sharp edges should be bound with gummed paper. Slides for use in a projection lantern can be made from the best pictures; and this task could be undertaken by the school's photography club. The Department of Extension, University of Alberta has a number of collections of slides of geological and geographical interest. These may be borrowed upon request.

2. Each pupil should be encouraged to keep a scrap book for items of geological interest. These items should not be confined only to pictures, but news accounts of survey parties, prominent geologists, mineral production, etc., should be included. Greater interest in this activity can be obtained by allowing the students to look at each other's scrap books for 10 minute periods several times a year.

3. Evaporate a few drops of tap or well water in a watch glass or clean glazed saucer and note the residue. This residue is a mixture of salts having lime present in the greater proportion. What is the origin of these salts?

4. Find other examples of movements of the earth's crust besides those mentioned in this work.

5. Make a collection of fossils which are found close to your home. Do they indicate marine or continental conditions at the time when they lived at that place; i.e. did the animals now found fossil live in the sea or on land in fresh water? If cases for keeping these fossils are not available, it is a good plan to glue the smaller remains to a piece of smooth board of appropriate size. Then cover board and fossils with a coating of varnish or shellac, and hang up in the room. Wash under the tap to remove dust. The names of the fossils and the place where found may be recorded on the back of the board; or a number may be assigned to each fossil, and a record of it kept

in a book. The following information should be recorded for each specimen: Date, common name (clam, coral, etc.); scientific name; rock formation in which it was found; place where found; collector's name.

6. Notice the attitude (dip) of any strata which are exposed. Are they flat or tilted? Can you estimate the angle at which the rock layers are tilted (measure from the horizontal downwards). An instrument for measuring the dip of strata is called a clinometer, and one can easily be constructed in this manner. Out of stiff cardboard cut a rectangle about 3"x4". Place the straight edge of a semi-circular protractor along a longer edge of the cardboard and make a tracing of the protractor. Graduate the arc in five degree intervals calling the middle of the arc 0° and each end of it 90°. From the centre of the circle suspend a pendulum made of a silken cord and a piece of lead foil, and make it long enough so that it swings below the graduated arc. To take a reading of the dip place the bottom edge of the clinometer on a bedding plane of the rock and read the angle that the cord cuts the arc. Be careful to take the greatest inclination of the stratum; this is obtained by pivoting the card on one corner. Express the dip in degrees along with the direction in which the strata are dipping; e.g., dip 35°W. means that the dip is to the west. A line at right angles to the dip is the strike, and can be obtained by drawing a line on the rock at right angles to the clinometer when making a reading of the dip. The line of strike is always horizontal, and its direction can be estimated by using a compass. The strike gives the true direction of the rock outcrop.

7. Look carefully for anticlines, synclines, smaller folds, faults, bedding planes, and stratification wherever bed rock is exposed. Note the position of the most conspicuous stratum. If it persists for some distance and is easily distinguished, it might be of use as a key bed.

8. Obtain geological reports and maps of your district from the Department of Mines and Resources, Bureau of Geology and Topography, Ottawa, or from the Department of Lands and Mines, Edmonton. Observe what rock formations make up bed rock, where there are contacts between these formations, and where there are rock outcrops; moreover visit these places, if possible, to see these features for geology is anything but an abstract subject.

9. Make a collection of the different kinds of rock which occur in various formations. Learn to recognize these types so that you are able to identify a formation by the rock of which it is composed.

10. Make a large chart of the Geological Time Table, and place it on the front wall of the classroom. On it should be shown the groups, systems, epochs, formations, estimated time, and important life forms.

11. Make charts of cardboard about 12"x15" to illustrate the more important forms of life of the different periods. Each pupil may be assigned one period, and the completed charts arranged in series on the walls. A selection of the life forms can be made from any recognized book on geology such as "Elementary Geology" by Coleman and Parks.

12. Draw maps of North America to show the distribution of land and sea during each of the geologic periods. These maps may be of the same size as the charts in No. 11, and may be placed on the walls of the room, where they will serve to impress upon the students the fluctuations that have occured in land and sea areas.

13. Make charts to show the development of such animals as the horse, man, elephant, etc., through the different epochs. This information can be obtained from texts, science periodicals, etc.

14. Draw a cross-section of the earth's crust to show the rock formations in your district. Get this information from the maps and reports of the Geological Survey which were obtained for No. 8. Let the cross-section take in a distance of about 10 miles to a depth of about 6,000 feet, and use a horizontal and vertical scale of about one inch to the mile.

15. Make two rectangular boxes out of white cardboard. Let each represent a block of the earth's crust; on one show a thrust fault and on the other a normal fault. Colour in the strata in different shades.

16. An apparatus to demonstrate the production of folds and faults can be simply devised. Make a strong wooden box with one detachable side. The box should be about three inches wide, five inches high, and 10 inches long. Fit into one end of the box a wooden block that just fits the box; and by means of nuts and bolts rig up a screw arrangement which will push the block towards the opposite end of the box (by attaching the nuts to the inside end of the box). Pour into the box alternately thin layers of variously coloured paraffin and plaster of Paris. Fill the box with lead shot or other heavy material such as moist sand, and then apply pressure to the layers by turning the screws. Push in the wooden block a few inches, remove the detachable side of the box, and observe the folding and crumpling of the layers. This device also illustrates the production of certain types of mountains.

GEOLOGICAL TIME TABLE FOR ALBERTA

GROUP (Era)	SYSTEM (Period)	SERIES (Epoch)	FORMATION (Age)	ESTIMATED TIME (In Years) Duration	ESTIMATED TIME (In Years) Total Since Epoch Began	DEVELOPMENT OF IMPORTANT FORMS OF LIFE	IMPORTANT MINERAL DEPOSITS
CENOZOIC (Era of mammals and flowering plants)	Quaternary	Recent		20,000	20,000	Rise of civilized man.	Clay, peat, nitrates, placer gold.
		Pleistocene		980,000	1,000,000	Periodic glaciation; rise of primitive man; extinction of many species of mammals such as the mastodon.	Gravels; clay.
	Tertiary	Pliocene		6,000,000	7,000,000	Man originated in the Pliocene. During the Tertiary Period primitive mammals, birds and plants were being differentiated into groups such as the cat family (cats, tigers, lions, etc.), dog family, etc. Modern forms have developed from these.	Oil in United States, Russia, Iraq; coal in Saskatchewan and British Columbia; gold in United States; clays in Saskatchewan.
		Miocene		12,000,000	19,000,000		
		Oligocene	Cypress Hills conglomerate	16,000,000	35,000,000		
		Eocene	Paskapoo sandstone	20,000,000	55,000,000		
MESOZOIC (Era of reptiles, ammonites and cycads)	Upper Cretaceous	Montana	Edmonton sandstone Bearpaw shale Belly River: Pale beds Belly River: Foremost beds Belly River: Pakowki shale Belly River: Milk River sandstone	40,000,000	95,000,000	Specialization of dinosaurs; some attained great size. Ammonites (a kind of shellfish) die out. Vegetation was sub-tropical.	Oil in Mexico, United States; **coal in Alberta** and British Columbia; copper of western United States. **Gas in Alberta.**
		Colorado	Alberta shale				
	Lower Cretaceous		Blairmore sandstone Kootenay coal measures	25,000,000	120,000,000	Rise of flowering plants and trees.	Oil in Mexico, United States, Alberta; **bituminous sands and coal in Alberta**; copper in western United States.
	Jurassic		Fernie shale	30,000,000	150,000,000	Reptiles dominate air, land and sea. Birds have teeth. Many sharks in the sea.	Iron of Great Britain and France; gold, silver, lead, zinc of southern British Columbia; oil in United States.
	Triassic		Spray River shale	30,000,000	180,000,000	Rise of dinosaurs; first mammals appear.	Oil in United States; **gypsum in Alberta.**
PALAEOZOIC (Era of shelled animals, fishes and ancient plants)	Permian			25,000,000	205,000,000	Rise of land vertebrates; glaciation in southern hemisphere.	Copper and potash of Germany and western United States; oil in United States.
	Carboniferous	Pennsylvanian	Rocky Mountain Quartzite	35,000,000	240,000,000	Primitive reptiles, insects; maximium development of crinoids.	Coal in Great Britain, the Maritimes, and United States; oil and gas in United States; salt in the Maritimes; **oil and gas in Alberta.**
		Mississippian	Rundle Banff shale	50,000,000	290,000,000	Abundant vegetation—coal forming.	
	Devonian		Minnewanka Ghost River	50,000,000	340,000,000	Oldest known land plants. Rise of amphibians; corals abundant.	Oil and gas in United States and **Alberta**
	Silurian		Brisco (in B.C.) Fitzgerald dolomite (in northern Alberta)	40,000,000	380,000,000	Armoured fishes, lung fishes, and the rise of air-breathing insects.	Oil and gas in United States; iron in eastern United States; **salt and gypsum in Alberta** and other parts of Canada.
	Ordovician		Beaverfoot Glenogle shale Goodsir shale	90,000,000	470,000,000	Graptolites abundant; rise of cephalopods; trilobites and brachiopods abundant; first fish appear.	Oil and Gas in United States and Ontario; lead and zinc in United States; iron in Newfoundland; building stone.
	Cambrian	Upper Cambrian	Ottertail limestone Chancellor shale Sherbrooke limestone Paget limestone Bosworth shale and limestone	30,000,000	500,000,000	Trilobites and brachiopods common. Algae and seaweeds abundant.	Oil in United States.
		Middle Cambrian	Eldon limestone Stephen shale Cathedral limestone	20,000,000	520,000,000		
		Lower Cambrian	Mt. White shale St. Piran quartzite Lake Louise shale Fairview sandstone and conglomerate	20,000,000	540,000,000		
PRE-CAMBRIAN (Era of primitive life)	Late		Hector shale Corral Creek sandstone	200,000,000	740,000,000	Primitive aquatic plants and invertebrates; fossils very rare.	Gold, silver, copper, nickel of eastern Canada; gold and copper of South Africa; radium, gold and silver of Northwest Territories; iron in United States.
	Early			1,000,000,000	1,740,000,000		

FIG. 10

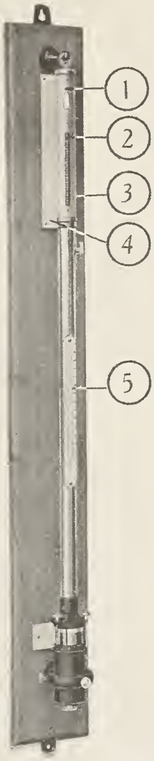


FIG.1

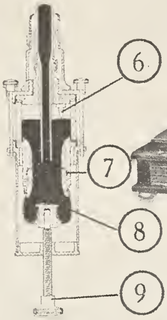


FIG. 2

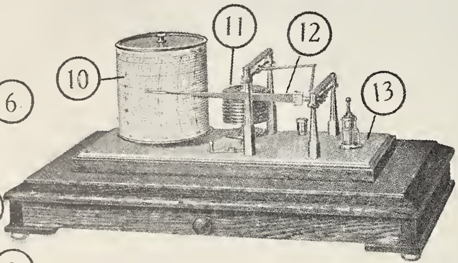


FIG. 3

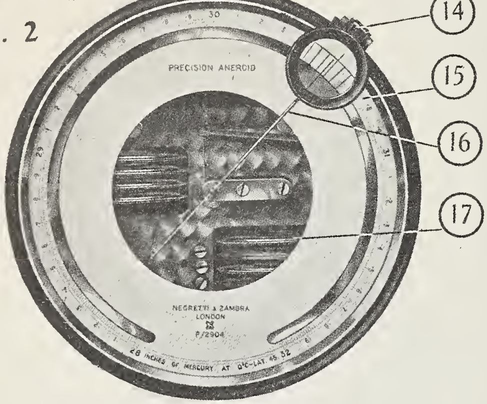
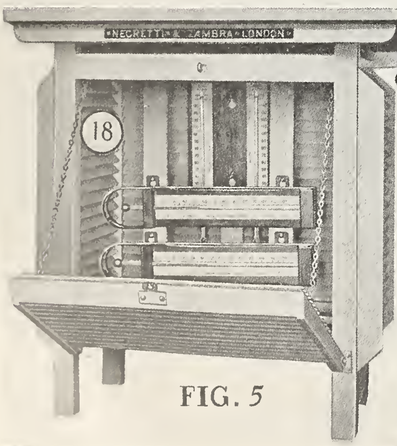


FIG. 4



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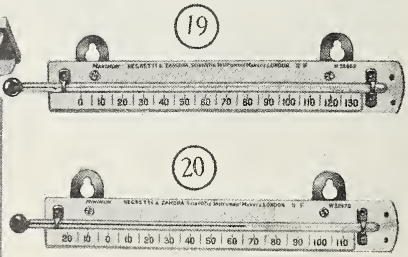
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MINIMUM NEGRETTI & ZAMBRA Scientific Instrument Makers LONDON

FIG. 6

Fig. 1, a Cistern Barometer—(1) a brass cylinder containing the tube, (2) aperture in the cylinder through which the height of the mercury in the tube may be seen, (3) a scale on the side of the aperture by which the height of the mercury above the ivory point in the cistern may be measured, (4) glass reflector, (5) thermometer.

Fig. 2, a Diagram of the Cistern of a Cistern Barometer—(6) ivory point marking the zero of the scale, (7) box wood cylinder, (8) a leather bag, (9) adjustment screw.

Fig. 3, Automatic Recording Barometer—(10) revolving recording drum, (11) diaphragm, (12) pen arm, (13) brass plate.

Fig. 4, Aneroid Barometer—(14) Magnifying lens, (15) scale, (16) tubular pointer, (17) corrugated diaphragm.

Fig. 5, Stevenson Screen—Containing maximum and minimum thermometers and Hygrometer—(18) louvres.

Fig. 6, Thermometers—(19) Maximum, (20) minimum.

PLATE I

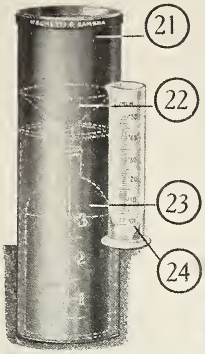

FIG. 7

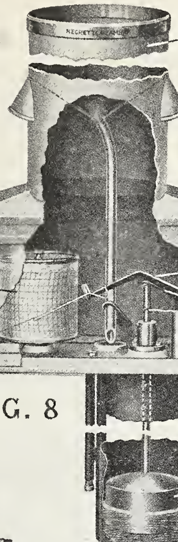

FIG. 8

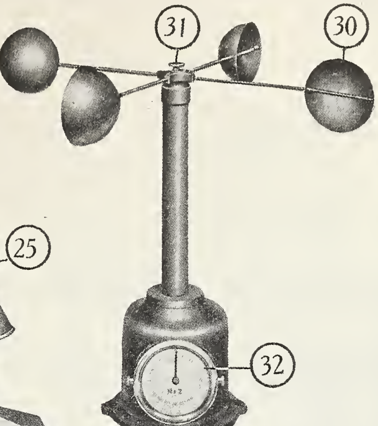

FIG. 10

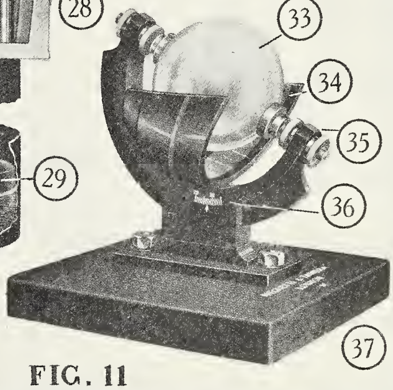

FIG. 11

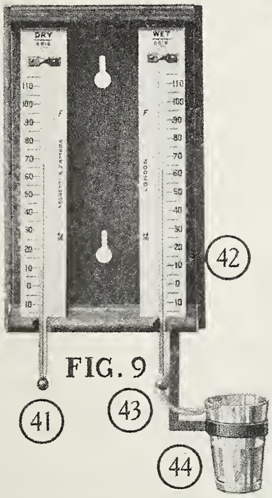

FIG. 9

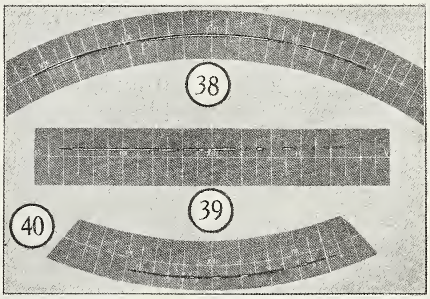

FIG. 12

Fig. 7, Rain Gauge—(21) brass cylinder 5 to 8 inches in diameter, (22) copper funnel, (23) glass bottle for collecting rain, (24) a graduated measuring glass.

Fig. 8, Automatic Recording Rain Gauge—(25) brass cylinder, (26) revolving recording drum, (27) pen arm, (28) pallet and stud, (29) float.

Fig. 9, Wet and Dry Bulb Hygrometer—(41) dry bulb, (42) wet bulb thermometer, (43) wick, (44) vessel containing water.

Fig. 10, Anemometer—(30) hemispherical cups, (31) spindle, (32) counter-mechanism which registers velocity in miles per hour.

Fig. 11, Campbell-Stokes Sunshine Recorder—(33) glass sphere, (34) bowl for holding the recording cards, (35) semi-circular arc, (36) scale for adjusting the arc to the right latitude, (37) brass base plate.

Fig. 12, Sunshine Recording Cards—(38) Summer, (39) spring and fall, (40) winter.

PLATE II

CHAPTER II

* * *

THE ATMOSPHERE

8. **Composition and Function.** — The atmosphere is a mixture of gases; at sea level the proportions are: nitrogen (over 78%), oxygen (almost 21%), argon (nearly 1%), carbon dioxide (.03%), rare gases (.01%), and water-vapor in varying amounts. These proportions vary with the altitude. About 70 miles above the earth's surface the atmosphere, some scientists believe, is composed entirely of the light gases, hydrogen and helium.

Several valuable functions are performed by the atmosphere: (1) It provides a medium for the transmission of sound. An airless world would be a soundless world. (2) It protects us against meteors. Every day thousands of meteors, travelling at a speed many times that of a rifle bullet, enter the atmosphere. Only an occasional one, however, reaches the earth's surface, the bulk of them being burned by friction with the air. Such meteors are popularly known as "shooting stars." (3) It conserves the earth's heat. Air is a poor conductor of heat. Were it not for the atmosphere much of the heat of the earth would be immediately lost, especially from that side away from the sun. (4) It carries moisture from place to place. Without the atmosphere there would be no rain or other precipitation. (5) It provides a medium of transportation for man, birds, bats, winged insects, bacteria, yeasts, spores, and winged and tufted seeds. (6) It is the home of germs, spores, etc.

The various gases comprising the air have functions of their own. Nitrogen fixed in the soil as nitrates is required for plant growth. Animals, because they depend upon plants for food, are indirectly dependent on nitrogen. Oxygen is vital to animals and plants, in releasing energy by slow combustion. It brings about the decay of plant and animal remains. It produces energy in the internal combustion engine by the rapid oxidation of fuel. Argon and nitrogen, being inert gases, serve to dilute the oxygen. Carbon dioxide is required by plants for growth, as it is from this gas combined with water that they manufacture starch, sugar, and cellulose. Water vapor is the source of precipitation (rain, snow, etc.) Some of the rare gases such as neon are used in electric light signs.

9. **Weight and Height.**—The vertical depth of the atmosphere is estimated to be about two hundred miles. It is divided into the troposphere and the stratosphere. The former extends about six miles above the earth, and the latter the remaining distance. The stratosphere contains no water vapor; hence clouds occur only in the troposphere. The temperature of the troposphere decreases with elevation, falling as low as 75° F. below zero at its outer limit. Beyond this in the stratosphere the temperature remains about the same.

Because air is matter and therefore has weight, it exerts pressure. This pressure on any area of the earth's surface is equal to the weight of the air above that area. At sea level the average pressure is about 14.7 pounds per square inch or 1033.6 grams per sq. cm. As the air above a point rests on the air below, it compresses it, and therefore the density of the atmosphere decreases with altitude. The density is greatest at sea level. It decreases rapidly as one ascends, one-half of the earth's atmosphere resting below a ceiling 3½ miles above sea level, and nine-tenths of it below one ten miles high.

Pressure is measured by means of a barometer. Illustration of three types of these are given in Plate 1. Fig. 1 is a Cistern Barometer. Note the names of the parts below the plate. Fig. 2 is a diagram of the cistern. Note that by means of an adjustment screw the level of the mercury in the cistern may be adjusted at zero before a reading is made from the scale. Fig. 4, Plate 1, illustrates the aneroid barometer. Other illustrations of this instrument are given in Fig. 11.

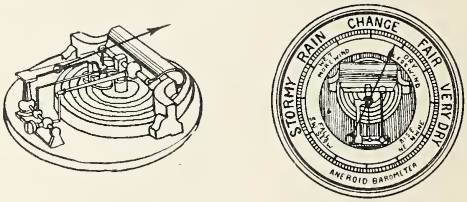

FIG. 11

Aneroid barometer.

It consists essentially of a small metallic drum with flexible corrugated sides. From this drum the air has been partially exhausted. If the air pressure rises, the sides of the drum are pressed more closely together; if the pressure falls, the sides are pushed outwards. This motion, by means of a set of levers and chains, is transferred to a pointer on a circular scale graduated in inches and centimeters to agree with the mercury barometer. Fig. 3, Plate 1, and Fig. 12 illustrate the barograph—an automatic pressure-recording device. In this instrument a pen point presses against a roll of paper on a cylinder revolved by clockwork, and gives a continuous record of changes in pressure.

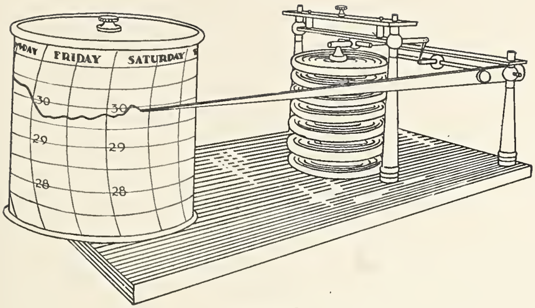

FIG. 12

Barograph, a self-recording barometer.

The mercury barometer is more accurate than the aneroid, but the latter is more sensitive in that it reacts more quickly to changes in pressure. An aneroid barometer is also much more convenient to transport, as it is smaller, and can be carried in any position. For these two reasons it is used as an altimeter by airplane pilots and surveyors to measure height.

Isobars are lines joining points on the earth's surface that have equal barometric pressure. They are usually closed curves, forming more or less concentric circles or ellipses. They are one of the important features of a weather map, and are designed to show graphically the weather conditions at any given time and place (Fig. 96).

10. **Humidity.**—The humidity of the air is the moisture content of it. In some places the humidity is regularly quite high, and such places have frequent rains. In other places the humidity is low, and rains are few. The carrying capacity of the air varies in accordance with its temperature. Hot air can hold much more moisture than cold air. If warm air is made quite moist and then cooled, a temperature will be reached at which the air is holding all the moisture it possibly can at that temperature. The air is then said to be **saturated** with moisture. If the temperature be lowered still further, the air will not be able to hold all the moisture and some will condense to form dew. The temperature at which condensation begins to take place is called the **dew point.**

Relative humidity is the proportion of water vapor present in the air to the total amount of water vapor that the air could hold at the same temperature. This is expressed as a percentage. If the temperature were raised and the amount of moisture in the air remained the same, the relative humidity would fall, because at the higher temperature more moisture would be necessary to saturate the air. Relative humidity is usually expressed as a fraction or ratio, thus:

$$\text{Relative humidity} = \frac{\text{Amount of moisture in air}}{\text{Amount required to saturate air}}$$

Relative humidity is measured by means of the hygrometer. The simplest and most common type is the Wet and Dry Bulb Hygrometer. This consists essentially of two thermometers. The first is exposed to the air like an ordinary room thermometer; the bulb of the second is covered with a wick, kept moist by having the other end immersed in water. Moisture evaporates from the wick, withdrawing heat from the bulb to convert the liquid water into vapor. The drier the air (that is, the less its humidity), the faster the water will evaporate from the wick. As evaporation proceeds, the temperature of the wick will be lowered and the wet bulb will register lower than the dry bulb. If the difference is great, the indication is low humidity. If the difference is small, humidity is high. Thus the greater the difference in the temperatures of the two thermometers, the less the relative humidity will be.

The construction of the wet and dry bulb hygrometer is shown in Fig. 9, Plate II. To find the relative humidity the temperatures of the two thermometers are taken and referred to a table which gives the corresponding relative humidity.

Humidity is very important to health. In our cold Canadian winters the air at low temperatures can hold very little moisture. If this air is heated, and the temperature raised from possibly many degrees below zero to room temperature, and if no additional moisture is added, the relative humidity of the air will be very low, because at the higher temperature, the air can hold much more moisture than at the lower. In such dry air moisture from the surface of the skin evaporates very rapidly, and in so doing uses up a great deal of heat from a person's body. This makes him feel much colder than he would if the humidity were greater, and the moisture not evaporating from his skin so rapidly. On the other hand, too high a relative humidity retards evaporation, with the result that a person feels uncomfortably warm. Relative humidity should be from 55 to 65 per cent.

11. **Rain and Snow.**—Water vapour is continually entering the atmosphere from exposed bodies of water such as lakes and seas, from transpiration of plants and breathing of animals, from the combustion of fuels and from other sources. This moisture condenses again as dew (mentioned above), frost, hail, rain or snow. Moisture, however, does not change from gas to liquid very readily unless it has something on which to condense, such as the cold ground or

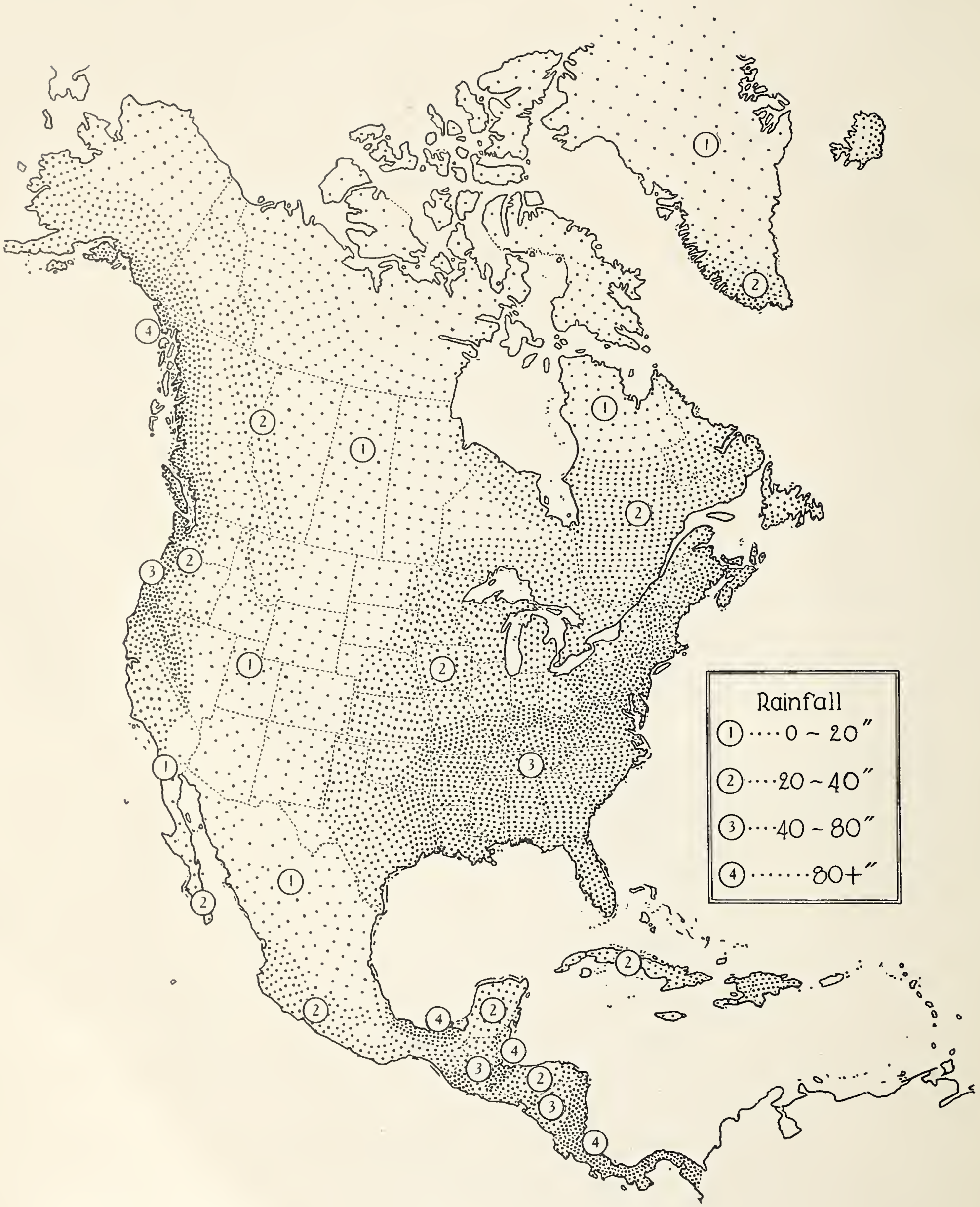

FIG. 13

Rainfall map of North America.

plant leaves. In the air tiny dust particles serve this purpose, and are called nuclei (singular—nucleus). About these particles, moisture condenses to form cloud globules. A cloud consists of billions of these cloud globules, which are so small that they are supported by the air. Many of these globules join to form a drop of water large enough to fall as rain, or each one may grow by condensation of more moisture. Rain, then, is a continuation of the process of cloud formation.

But why should air become so cool as to cause the moisture or water-vapour to condense? Warm air near the surface of the earth will expand, and expanding become lighter and cooler. As it becomes lighter it rises, expands still more because the pressure is less, and becomes so cool that moisture condenses. Or a current of cool air may strike a current of warm air and cool it sufficiently to cause moisture in the warm current to condense. This is what causes the dense fogs off the coast of Newfoundland. The cold air currents sweeping down from Labrador and Baffin Land meet the warm air currents following the Gulf Stream, and the result is that the latter is cooled so much that a large part of the moisture it carries is condensed.

Another cause of the air's cooling is its forced rise to higher altitudes in passing over mountains that bar its way. Thus the northwest and west winds off the coast of British Columbia strike the Rocky Mountains and are forced up and over them. As they rise the air becomes colder, causing the moisture to precipitate as rain. By the time the winds sweep over the mountains, they have very little moisture left. Thus the annual rainfall on the west side of the mountains may be as much as one hundred inches; on the east side as little as ten.

Over the surface of the earth the rainfall may vary from practically zero to as much as forty feet per year. Fig. 13 shows the precipitation annually in various sections of North America.

Rainfall is measured by means of a rain gauge. This is a very simple instrument, consisting essentially of a funnel into which the rain falls, a bottle in which it is collected, and a graduate in which the rain is measured. It is illustrated in Figs. 7 and 8, Plate II.

When dew-point is below freezing point of water, precipitation takes the form of snow. That snow is not frozen rain is evident from an examination of a snowflake. A snowflake is really a crystal, and, as far as can be discovered, no two such crystals are ever quite alike. Snowflakes form very beautiful symmetrical patterns; they are invariably six-pointed. The structure of a snowflake is apparent from a study of Fig. 14.

Since snow may pack tightly or loosely, for scientific purposes snowfall is measured by the number of inches of water it will produce. Ten inches of snow is considered to equal one inch of rain.

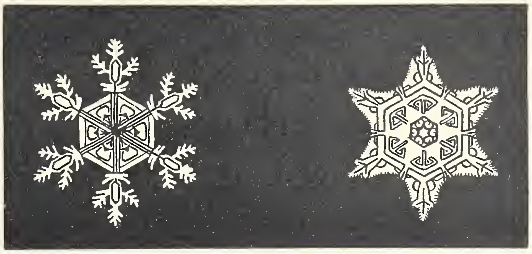

FIG. 14

Snowflakes—crystallized water; note the hexagonal form typical of all flakes.

12. **Temperature of the Atmosphere.** — The temperature of the atmosphere varies on the earth's surface from over 110° F. in some places to as low as 70° F. below zero in others. Also, the temperature decreases with altitude, as previously noted. The rate is about 1° F. for every 300 feet of ascent. But nowhere does the temperature fall importantly near absolute zero (459.4° F. below zero). The atmosphere, therefore, must receive heat from some other source or sources. These sources are the sun and the earth. The lowest temperatures occur in Siberia (500 miles east of the Lena River and just above the Arctic Circle), and in the Antarctic Plateau, where a temperature of 80 degrees Fahrenheit below zero has been recorded. The highest temperatures have been observed in desert regions—one of 127° F. in the shade was recorded in the Algerian desert, and in southern Arizona 120° F. is sometimes reached.

Modes of Warming and Cooling the Atmosphere: (1) Radiant Energy.—It is a well-known fact in science that the sun is the source of all the earth's energy. This energy is radiated from the sun and travels to the earth by a wave motion at the rate of over 186,000 miles per second. These waves are of several kinds; some of them are: (a) Ultra-violet rays, which effect chemical changes in plants and animals, (b) Light waves, which enable us to see; they make up the colors of the spectrum; (c) Infrared or heat waves, which, on striking a material substance are converted into heat—by which, in turn, the substance is warmed. It is with these heat waves that we are mainly concerned when we are considering the source of the earth's heat.

Some substances such as air, water, and window-glass are said to be transparent in that they allow light to pass freely through them. In a similar way, substances which allow heat waves to pass freely through them are said to be **diathermanous**. Air and glass are diathermanous, but water is not. It is **adiathermanous.** Water absorbs the heat waves and becomes warm; glass and air are not warmed by the passage of heat waves through them. Some substances, like water, are transparent but not diathermanous; other substances, like fog, are diathermanous but not transparent. Thus by using a plate which is sensitive to infra-red (heat) rays, instead of light rays, one can take clear pictures at night or through fog. As these pictures can be developed very rapidly, some navigators carry cameras using infra-red rays, which enable them to sight dangers obscured by darkness or fog, and so avoid collisions or prevent running their vessels into reefs and sandbanks.

Objects which are warmer than their surroundings radiate heat; thus the earth radiates into space the heat that comes to it from the sun. During the day it receives more heat than it radiates, and so the ground becomes warmer and warmer; but at night it receives no heat and radiates what it received during the day. In the long summer days, the ground becomes warmer day by day, for it receives more heat than it radiates. But in winter the reverse is true—in the long winter nights it radiates more than it receives. Also, as dark objects are better radiators of heat than light-coloured or shiny ones, the soil and rock radiate more heat than water, and so cool more quickly. This is one reason why land is colder than water in winter.

Shiny or light-coloured objects reflect heat but dark objects absorb it. Hence we use reflectors behind the resistance wire of an electric heater, and we wear light-coloured clothes during the hot summer. Applying this principle to land and water, we find that water reflects much of the heat that strikes its surface, but the land absorbs it, becoming warmer than the water.

In spite of the diathermancy of the air, it receives a certain amount of heat from the radiations which pass through ~~it because~~ dust particles in the air absorb some of the infra-red rays.

(2) **Conduction**.—In addition to the method of transference of heat by radiation dealt with above, heat is also transferred by conduction and convection currents. By conduction, heat is transferred in a substance by contact of the particles, but without any perceptible movement of the particles. Some substances are better conductors of heat than others. Metals are good conductors. Other solids and most liquids are poor conductors, and gases are extremely poor conductors of heat, but, nevertheless, conduct a certain amount of heat to the air, thus helping to warm the atmosphere. Soil is such a poor conductor of heat that in northern latitudes it remains permanently frozen a few feet below the surface.

As noted above, air is a very poor conductor of heat, and so it forms a very good insulating medium if convection currents can be prevented from forming in it. A dead air space is left between the double walls of houses, and this helps to keep the heat in in winter and to keep it out in summer. However, as the air space is rather large, more effective insulation is obtained by filling the space with sawdust, shavings, moss, hay, etc. In these the air spaces are made too small for convection currents of much account to be set up. At the same time the transfer of heat within the material itself is almost negligible.

(3) **Convection Currents** are set up in a fluid (a liquid or a gas) by unequal heating. The heated portion expands, becoming less dense or lighter than the surrounding fluid. The attraction of gravity is greater on the cooler (therefore heavier) portion and pulls it downwards, forcing the warmer portion upwards. This cooler portion in turn is warmed, expands and is forced upwards. In this manner a circulation is set up in the fluid. As the warmer portion rises, it distributes its heat to other parts of the fluid. In this way the heat of the air is

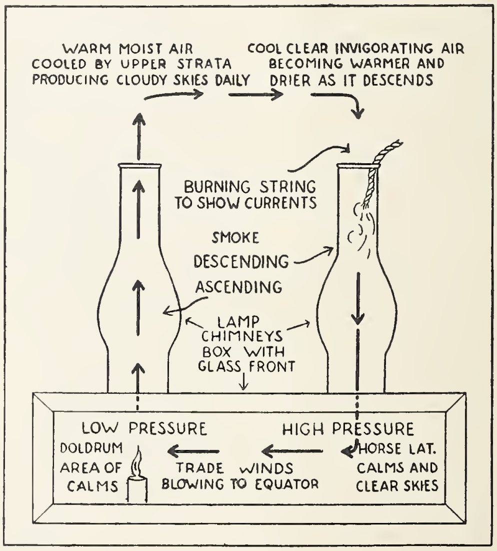
WARM MOIST AIR COOLED BY UPPER STRATA PRODUCING CLOUDY SKIES DAILY
COOL CLEAR INVIGORATING AIR BECOMING WARMER AND DRIER AS IT DESCENDS
BURNING STRING TO SHOW CURRENTS
SMOKE
DESCENDING
ASCENDING
LAMP CHIMNEYS
BOX WITH GLASS FRONT
LOW PRESSURE
HIGH PRESSURE
DOLDRUM AREA OF CALMS
TRADE WINDS BLOWING TO EQUATOR
HORSE LAT. CALMS AND CLEAR SKIES

FIG. 15

Apparatus to show convection currents in air and the production of winds.

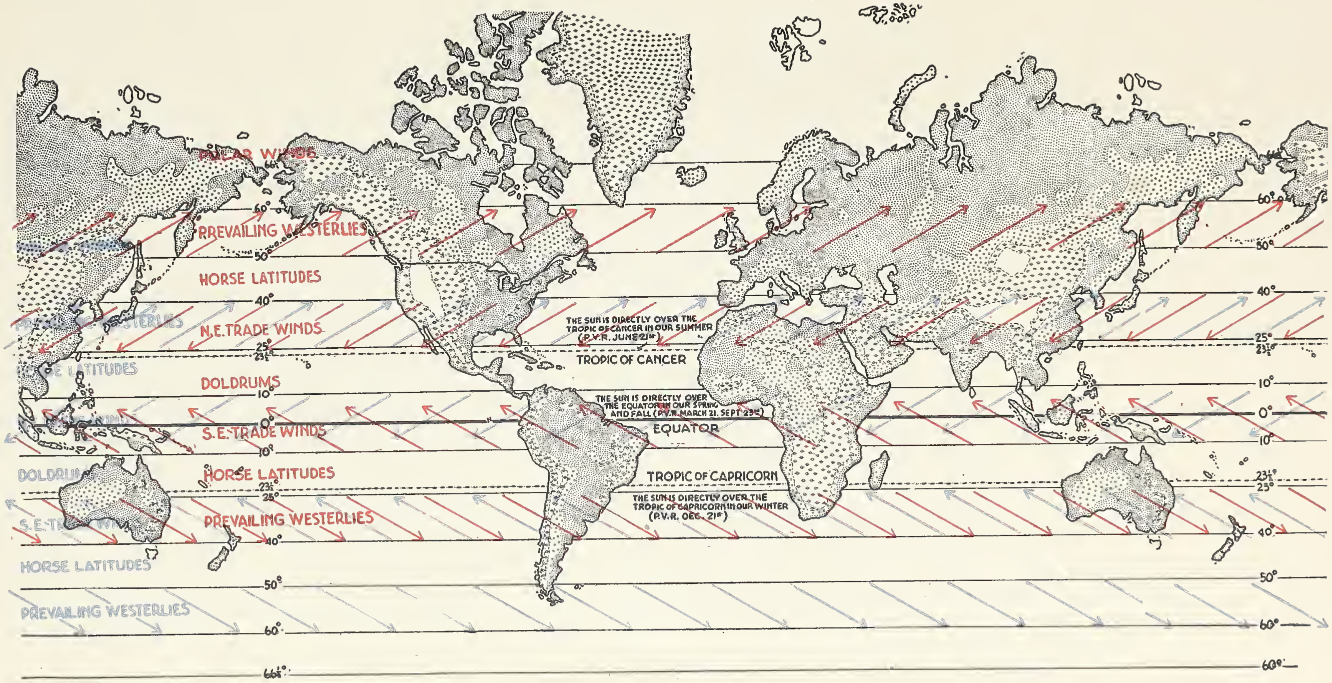

FIG. 17

WIND BELTS OF THE WORLD

World winds in "our" summer (red), and winter (blue), with the sun over the Tropics of Cancer and Capricorn respectively.

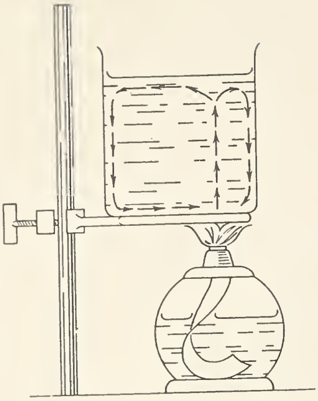

FIG. 16

Experiment illustrating convection currents in water, and the movement of ocean currents.

increased during hours of daylight or in summer. Figs. 15 and 16 illustrate the production of convection currents in air and in water.

Winds and ocean currents are convection currents on a large scale. As ocean currents are more properly dealt with in connection with the hydrosphere, only winds will be dealt with here.

During a warm day, because the land becomes warmer than the water, the air above the shore of a lake or other large body of water will become much warmer than the air above the water. Accordingly, it rises and is replaced by cooler air blowing in from the lake, bay or sea. Thus a sea breeze is set up during the day.

At night, however, circumstances are reversed. The land has given up its heat rapidly and is now cooler than the water. Therefore the air over the water being warmer, rises, and is replaced by air from the land, and so a land breeze is created. Land and sea breezes are of local occurrence.

Monsoons are seasonal winds which change direction from summer to winter. During the summer the land is warmer than the sea, and the moisture-laden wind blows off the sea, forming the summer monsoon, which is the wet season. In winter the land is cooler than the water, and the winds blow off the land; they are drying winds. These winds are developed on most continents, but the best development is in India.

Trade winds are caused by the heating of the air above the thermal equator. The hot air rises and is replaced by air rushing in from the north and south. On account of the rotation of the earth these winds are deflected to the west and are known as the northeast and southeast trade winds. As the thermal equator moves north in summer and south in winter, the belts of trade winds migrate with it. The hot air which rises cools and descends just north and south of the trade wind belts to form two belts of calms, known as the **horse latitudes.** The region from which the hot air rises is a belt of calms called the **doldrums** (Figs. 15, 17).

North and south of the horse latitudes are two other wind belts, the **prevailing westerlies.** North and south of these winds again are the **circumpolar winds** of which little is known at present. These wind belts are illustrated in Fig. 17.

The velocity of a wind is measured by an anemometer (see Fig. 10, Plate II). The hemispherical cups rotate on an axis, which in turn operates a mechanical counter. Thus the velocity of the wind is registered.

13. **Causes for Differences in Temperatures of the Earth: (1) Position of the Sun in the Heavens.**—(a) Position of the sun varies from morning to night. We all know that it is warmer at noon than in the early morning or late afternoon and that bright days are warmer than cloudy ones. This is due to the intensity of the sunlight. In the early mornings and late afternoons the sun's rays strike the earth at a considerable slant and, therefore, have much more of the earth to warm than they do during the middle of the day. An examination of Fig. 18 will make this clear. Notice how much more surface the rays have to cover early and late in the day compared with the amount of surface they warm at midday.

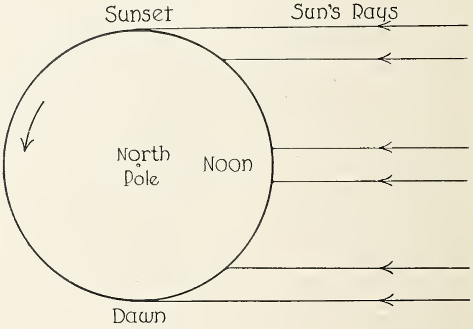

FIG. 18

Diagram to illustrate changes in the sun's heat during the daytime. The same amount of heat covers the smallest area when the sun is directly overhead; therefore temperature is highest then.

(b) From season to season. The reason for the coldness of the atmosphere in winter is similar to that given above for changes in temperature during the day. That part of the earth which is experiencing winter is tilted away from the sun; that part enjoying summer is inclined toward the sun. This is shown in Fig. 19. Notice how much surface the rays have to heat in the northern hemisphere, where the earth is tilted away from the sun and winter prevails. Compare this with the lesser surface heated by the sunlight in the southern hemisphere, which is experiencing summer.

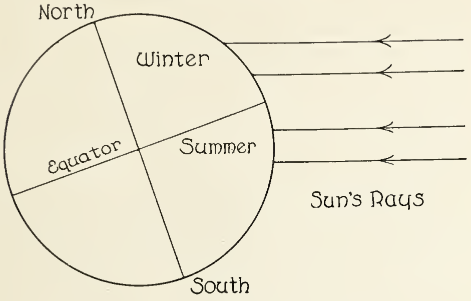

FIG. 19

The earth's axis is tilted away from the sun; so a part of the earth's surface receives the sun's rays directly at one time of the year and obliquely at another; thereby giving rise to the seasons.

(c) From place to place. Sometimes the sun is rendered less intense through being obscured by clouds. These clouds may form just a very thin film, so slight as to be hardly noticeable; at other times they may be very thick.

The number of hours of sunlight is registered by the Campbell-Stokes Sunshine Recorder, which consists mainly of a transparent glass sphere. This acts as a lens and concentrates the sunlight on a strip of paper graduated in hours. As the sun moves across the sky it burns its own record on the paper. The unburnt paper represents the time the sun is obscured by clouds. (See Figs. 11, 12, Plate II).

(2) **Latitude.**—Why is it that the farther away from the equator one goes the colder it becomes? Some people would say that it is because you are getting closer to the Poles, which are always cold. But this is just another way of saying that you are getting away from the equator. The reason is that at high latitudes the sun's rays strike the surface of the earth at a slant; at or near the equator they strike at almost a right angle. Thus the reason for the increased cold at the high latitudes is similar to the reason for the low temperatures morning and evening, and during the winter.

(3) **Altitude.**—Those of us who have seen the Rockies in summer have perhaps noticed snow on some of the peaks. Thus we were given emphatic proof that altitude has a very important effect on temperature. In fact, the higher we go, the colder it becomes. This was mentioned before in discussing the troposphere and stratosphere and the temperature of the atmosphere. In the Torrid Zone mountain peaks above sixteen thousand feet are covered with snow throughout the whole year. The line above which there is perpetual snow is called the **snow line.** It is lower in the temperate zones and reaches sea level in the polar regions.

(4) **Nature of the Soil.** — Certain soils are called cold; others are named warm soils. Cold soils are those that require a great deal of heat to warm up. This may be because they are naturally poor conductors of heat, as for example, heavy clay or "gumbo" soils. Or it may be because they are tightly packed so that the warm air cannot circulate through them. Finally, they may contain a large percentage of water, which itself is a very poor conductor of heat, and requires much heat to warm it.

Warm soils absorb and transmit heat quickly. They are just the opposite of cold soils, being comparatively light, dry and well aired, allowing the warm air to circulate through them.

(5) **Exposure.** — By exposure is meant the direction or slope of the earth's surface. Very little of this surface is level. That which slopes to the sun will receive more heat and light than that which slopes away, as shown in Fig. 20. In the northern hemisphere the sunny slopes will face the south; in the southern hemisphere they will face the north. Deep valleys receive sunshine for only a few hours a day, but hilltops are exposed to the sun all day long, thus having an advantage that partially compensates for their greater altitude.

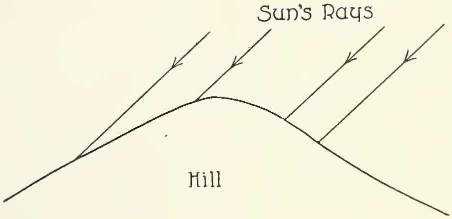

FIG. 20

The effect of slope on temperature: Northern slopes (on left in diagram) in the northern hemisphere receive less heat per square foot than southern slopes (on right) and are therefore cooler.

(6) **Influence of Bodies of Water.**—A large body of water exercises a moderating effect on climate, keeping the land cooler in summer and warmer in winter than would otherwise be the case. During the summer, because the water heats up slowly, it is cooler than the land, and so

tends to keep down the temperature of the land. In winter, because of its slowness in cooling down, water tends to be warmer than the land, and so it keeps the land from becoming as cold as it otherwise would be. This moderating influence of large bodies of water, however, is itself subjected to variation by cold or warm ocean currents. Newfoundland is closer to the equator than England, and yet its winters are much more severe. This is because Newfoundland is subjected to the frigid effects of the Labrador and Greenland currents, whereas England enjoys the warming influence of the North Atlantic Drift, that warm current originating in the Gulf Stream.

We usually think that the North Pole is the coldest place on earth because it is the farthest north. However, the temperature at the South Pole is very much lower. There are two reasons for this condition: First, the South Pole is located in the centre of a continent larger than Europe, far away from the moderating influence of any body of water, whereas the North Pole is in the middle of the Arctic Ocean. Secondly, the South Pole is at an altitude of several thousand feet, whereas the North Pole is at sea level. Therefore, the South "Pole of Greatest Cold" roughly corresponds with the South Geographic Pole. This is not so in the Northern Hemisphere, where the "Pole of the Greatest Cold" is in Siberia, far from the ocean and in a mountainous district.

(7) **Nature and Direction of the Wind.**—The effect of wind on temperatures is a matter of common knowledge. Generally a north wind is colder than a south wind, as it blows from a region of lower temperatures. Winds blowing off ocean currents onto the land affect the climate of that place. Labrador and England are in approximately the same latitude; yet Labrador is much colder than England, as it is subject to winds blowing off the cold Labrador and Greenland currents, whereas England is in the path of the winds from the warm Gulf Stream.

14. **The Mapping of Temperature; Isotherms.**—Two meteorological instruments not yet mentioned are the maximum and minimum thermometers. These are shown in Fig. 6, Plate I. The maximum thermometer is designed to record the highest temperature of any given period of time. In construction it is very similar to an ordinary thermometer except for a constriction and kink just above the bulb. (Note this in Figs. 6, 19, Plate I). This allows the mercury, which is generally used, to expand as long as the temperature continues to rise; but as soon as it starts to fall contraction sets in, and the thread of mercury breaks at the constriction and remains in the stem, thus recording the highest temperature. After the reading is taken, the mercury is shaken into the bulb again.

Since mercury freezes at forty degrees below zero Fahrenheit, alcohol is generally used in the minimum thermometer. This instrument is also very similar to the ordinary thermometer, but in the stem is a little iron or porcelain rider. When the temperature falls, the alcohol flows back, and by surface tension the rider is dragged along with it. When the temperature rises, the alcohol flows forward past the rider, thereby leaving a record of the lowest temperature.

Both thermometers are hung in a horizontal position in a Stevenson Screen. This is to protect them from radiations from the sun or other objects, which would make them warmer than the surrounding air. This screen is shown in Fig. 5, Plate I.

After the temperatures have been found at a great many places, lines are drawn on a map connecting those places having the same temperature. These lines are called **isotherms.** They are not broken lines made up of straight segments drawn from place to place, but smooth curves, and do not cross each other. Isotherms are very useful in forecasting changes in temperature, and in summarizing average temperatures (Figs. 94, 95).

* * *

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Questions:

1. (a) Name the most important component gases of the atmosphere, and give the percentage of each.
   (b) Give six important functions of the atmosphere in general.
   (c) Give one particular function of each: nitrogen, oxygen, carbon dioxide, water vapor, neon.
2. (a) Where is the division between the troposphere and stratosphere?
   (b) Give the important features of each of the troposphere and stratosphere.
   (c) What is the air pressure at sea level?
   (d) Why does the density of the air decrease with altitude?
   (e) What is the air pressure at elevations of 3½ miles and 10 miles above sea level?
3. (a) Describe briefly the construction and operation of the cistern barometer.
   (b) Describe briefly the principle of the aneroid barometer.
   (c) What is a barograph? How does it operate?

(d) Give three advantages of the aneroid barometer over the cistern type. What advantage has the cistern barometer?

(e) What are isobars? What shape are they?

4. (a) What is meant by humidity? saturated air? dew-point? relative humidity?

(b) Describe briefly the construction and operation of the wet-and-dry bulb hygrometer.

(c) Why might dry air make one feel cold and moist air make one feel uncomfortably warm?

(d) What relative humidity is best for health?

5. (a) Write a note to explain the meaning of "water cycle".

(b) What are cloud globules?

(c) How are raindrops formed from cloud globules?

(d) How are the fogs off the coast of Newfoundland caused?

(e) Describe the construction of the rain gauge.

(f) Explain how snowflakes are formed. How many points has a snowflake?

(g) Colour Figure 13 using a different colour for each of the areas of varying precipitation.

6. (a) At what rate does temperature decrease with altitude?

(b) The temperature at the base of a mountain is 60°F. What is the temperature 3,000 feet higher?

(c) What are the sources of the atmosphere's heat?

(d) What regions have the highest temperatures?

7. (a) Name three important kinds of radiant energy.

(b) Give the meaning of diathermanous and adiathermanous. Exemplify.

(c) What is the work of conduction in warming the atmosphere?

(d) Explain how a convection current is formed in air. Apply this explanation to the formation of winds.

(e) Describe the use and operation of an anemometer.

8. (a) How does the position of the sun affect the temperature of the atmosphere in these cases: (1) from morning to night? (2) from season to season? (3) from place to place?

(b) Describe the construction and operation of the Campbell-Stokes sunshine recorder.

(c) Explain why temperature decreases with distance from the equator. Use a diagram.

(d) How does the nature of the soil affect temperature?

(e) What is meant by exposure? How does it affect temperature?

(f) How does the presence of large bodies of water tend to keep temperature moderate?

(g) How does the direction of the wind affect temperature?

9. (a) Of what use is a maximum thermometer? a minimum thermometer? What liquid is used in each?

(b) Draw a diagram of a maximum thermometer of the constriction type.

(c) Why are these thermometers hung in a Stevenson screen?

(d) What is an isotherm?

(e) Give two uses of isotherms.

Suggested Activities:

1. Moisten the inside of a graduate or test tube with water; then sprinkle iron filings into it so as to get as many as possible to adhere to the inside of the vessel. Invert the vessel in a beaker of water and immerse the mouth to a depth of about one inch. Measure the height of the air column. Allow the apparatus to stand for 24 hours, and again measure the height of the column of gas in the tube. Calculate the percentage decrease in the volume of the gas. Why did water rise in the tube? Does the remaining gas support combustion? Test it with lime water. What gas is it? What gas has been used up by the iron? Note the rusty appearance of the iron.

2. Heat a bottle of air or fill it with steam, and invert in a vessel of water. What part does pressure play in forcing water to rise in the bottle?

3. Find out where there is a barograph or thermograph in your district, and watch it in operation.

4. Stir a mixture of ice and water in a thin-walled tumbler, or better still in a metal vessel such as an overflow can, and note the temperature at which the surface becomes misty. This temperature is the dew-point. In what condition is the air immediately surrounding the vessel?

5. Construct a wet-and-dry bulb hygrometer, and find the relative humidity by referring to

the table on page 260 of Elements of Physics (Merchant and Chant).

6. Observe closely the form of different snowflakes. Are any two exactly alike?

7. How may photography using infra-red (heat) rays be used in the detection of enemy aircraft?

8. Obtain a glass prism, hold it in the sunlight, and observe the spectrum obtained. At which side are the infra-red rays? At which side are the ultra-violet rays?

9. Secure two large similar test tubes or two small bottles of colourless glass. Fill one with water, and into each put a thermometer. Place the bottles in the sun and allow to stand for some time. Why does the bottle containing water show a higher temperature than the other?

10. Note the difference in temperature between the chrome-plated parts of an automobile which is standing in the sun and the painted parts. How do you account for the lower temperature of the metal-plated parts?

11. What provision is made in your classroom for ventilation by means of convection currents?

12. Have you ever noticed while you were sitting or standing in front of a campfire at night that you were quite warm on one side from radiation from the fire, and that you were quite cool on the other side from the cold air coming in to the fire?

13. Investigate the differences in the temperatures of the soil at various depths up to five inches. What do you conclude regarding the conduction of heat in soil?

14. Why is alcohol used in some thermometers and mercury in others? Why is alcohol more commonly used?

15. Keep a daily record of the direction of the wind. Take the direction at the same time each day, say 12 noon. From which direction did the winds come most in summer and which in winter?

CHAPTER III

* * *

THE OCEAN OR HYDROSPHERE

15. **Extent.**—The surface area of the earth is 197 million square miles, and of this, the ocean covers 71% or 140 million square miles. The mean depth of the ocean is 12,480 feet, and the mean height of the land is 2,250 feet. If we suppose all the higher parts of the land to be cut off and filled into the oceanic depressions, the depth of the ocean around the whole world would be about 10,000 feet.

16. **Importance to Mankind.**—Water is necessary to sustain all life, and no matter whether the source of supply is a river, a lake, a spring or a well, the original source can be traced to the ocean. Mineral deposits, such as salt and gypsum, were deposited by arms of the sea on evaporation of the water. The ocean, once considered a barrier to communication, is now a great boon. It is a rapid means of communication, and also is the cheapest method of transportation. The world's greatest fisheries are found in the ocean on the continental margins. They are an important source of food and provide employment for a considerable population. Moreover the oceans have a great effect on climate. Regions near the sea have a more equable climate than those inland.

17. **Oceanography.**—This is the science of the ocean. It includes such studies as: depth, temperature, ocean currents, tides, ocean deposits and the composition of sea water. Many countries maintain oceanographic research institutes and send out expeditions to gather more information. Perhaps the most famous expedition is that of the "Challenger," sponsored by the British Government. It set out in 1872 to circumnavigate the globe, and its investigations covered a period of 3½ years.

18. **Instruments Used in Exploring the Ocean:**
(a) **Sonic depth finder.**—Formerly the depth of the ocean was found by letting a line of either hemp or piano wire, with a weight attached, sink to the bottom. Nowadays the depth is determined by sound waves. A large steel diaphragm built into the bottom of the boat is set vibrating by electromagnets. A sound wave is produced which travels to the ocean bottom and is reflected. The echo is picked up by microphones set in the vessel's hull and is carried to the head phones of the observer. An accurate timing device gives the exact time interval between the outgoing signal and the echo. Knowing the velocity of sound in sea-water, 4,840 feet per second, one can readily determine the depth of the ocean. To illustrate, if two seconds elapse between the production of the sound and its return, the depth at that place is 4,840 feet, for the sound wave has travelled to the bottom and back in that time.

(b) **Trawl and dredge.**—These are used for obtaining specimens of marine life at or near the bottom. The trawl has a large opening, as great as 50 feet across, and a large bag net. It can be towed at any desired depth.

The dredge is smaller, having a rectangular opening framed with iron, to which is attached a bag net. It is dragged along the bottom.

(c) **Water bottle.**—This is a device for obtaining a sample of the water at a required depth. The bottle holds about 300 c.c. (a little over half a pint), and is open at both ends. When it has been lowered to the required depth, a weight is slid down the line; on reaching the bottle it releases a catch which closes both ends of the bottle, and a sample of water is obtained at that depth.

(d) **Thermometer.** — Thermometers used in oceanography have to be of a strong construction to withstand the enormous pressure of the water at great depths. Two types are used:

The first type is used in the water bottle. The thermometer is enclosed in the bottle, which is surrounded with several concentric chambers. When the bottle is withdrawn, the water in the outer chambers insulates the water in the bottle against any changes in temperature.

The second type has an S-shaped bend in the capillary tube just above the bulb, and a constriction in the bend or near it. The thermometer is mounted in a frame. When it has been lowered to the desired depth, a weight is slid down the line. This weight releases a catch which reverses the frame through 180°. The mercury column in the tube is broken at the constriction and falls to the upper part of the tube (the lower part after reversal. This part of the tube being graduated, the temperature can be read from it.

(e) **Core sounding apparatus.**—Various devices are used for obtaining samples of sediments at the sea bottom. One way is to use soap or some other sticky material at the bottom of a weight lowered to the bottom. Another device, consisting of two cups, snaps shut on reaching the bottom and secures about a handful of mud. The disadvantages of these methods are that the samples are small and represent only the surface of the ocean bottom.

In the last two or three years an ingenious device has been invented for securing larger samples. This is the **core sounding apparatus,** and it consists essentially of a steel tube which is driven into the sediments at the bottom by an explosion of gunpowder. The explosive is automatically fired when the apparatus touches the bottom. The apparatus is lowered at the end of a line and drawn up by the same line. The sample is contained in a brass tube inside the steel tube, and is left inside this brass tube until, or even during, examination. After the explosion, and the removal of the apparatus from the water, the brass tube is taken out of the steel tube and replaced by another brass tube in preparation for another sounding. The sample is then examined by removing a longitudinal section of the brass tube.

Cores as long as ten feet have been obtained by this method. The apparatus has been used successfully at a depth of 15,900 feet, and there is reason to believe that it can operate at the greatest depths of the ocean. Some cores thus obtained represent sediment which has taken thousands and perhaps millions of years to accumulate, and therefore they are of great value to the geologist and oceanographer. It is of interest to know that glacial debris found in some cores taken in the Atlantic corroborates findings of those geologists who have studied the glaciation of the Pleistocene. A series of cores from Newfoundland to Ireland has been obtained by this means.

19. **Ocean Basins; the Sea-Floor:** (a) **Nature of the sea-floor.**—The sea-floor, as compared to the land, is quite smooth. Precipitous slopes are rare, being found chiefly in the vicinity of volcanoes, which rise here and there above the sea-floor. Some of these volcanoes rise above the surface to form islands. Examples of these are the Hawaiian Islands, Christmas Islands, Bermuda. The sea-floor is covered with sediment, which has been derived from the continents and from the skeletons of small animals and plants which live near the surface.

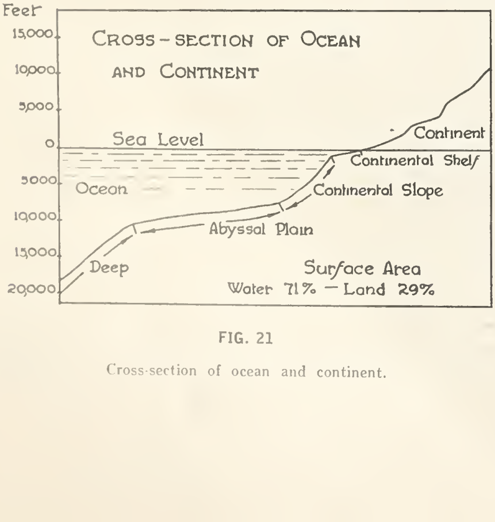

FIG. 21

Cross-section of ocean and continent.

The sea-floor is divided into four regions, according to the depth of the water. (Fig. 21). These are:

1. Continental shelf, 0 - 600 feet.
2. Continental slopes, 600 - 10,000 feet.
3. Abyssal plains, 10,000 - 18,000 feet.
4. Deeps, 18,000 feet and over.

The greatest depth of the ocean, 35,400 feet, was recorded east of Mindanao, one of the Phillippine Islands. This depth is greater than the highest elevation above sea-level, viz., Mount Everest, 29,002 feet.

(b) **Deposits of the ocean bottom:**

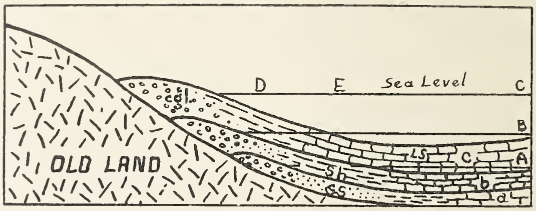

FIG. 22

Sedimentary deposits of the continental shelf with a stationary shoreline; gravel is deposited along the shore, then, in order, sand, clay and lime; these beds were deposited at the same time and are of the same age.

(1) **Rock fragments.** — These consist of gravel, sand and clay, which have been eroded from the continent and carried to the sea by streams, rivers, glaciers, winds and waves. These materials are deposited on the continental shelves in a regular order, the larger pebbles being dropped first, and the finest particles of clay being carried out the greatest distance. Beyond the clay deposits limestone is formed from the calcareous shells of marine animals and chemical precipitate. The shells may be cemented together by calcium carbonate precipitated from the sea water. Muds are deposited on the continental slopes.

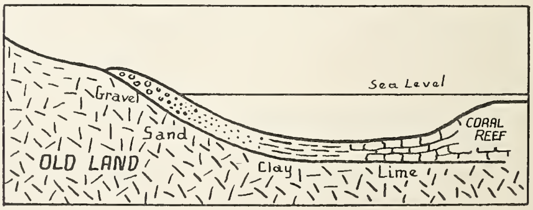

FIG. 23

Deposition of sediments in an invading sea caused by a sinking shoreline; a progressive overlap of the formations. Note the succession of rock types at D, viz., shale, sandstone and conglomerate, and at E, viz., limestone, shale and sandstone. Bed "a" was laid down when the sea level was at A, etc.

Cgl conglomerate, ss sandstone, sh shale, and ls limestone.

Fig. 22 shows the order of deposition. Fig. 23 shows that the land is sinking, for the limestone is being formed where formerly there was sand of the sea shore. Fig. 24 shows deposition with a rising shoreline.

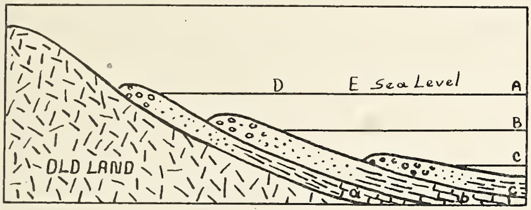

FIG. 24

Sedimentary deposits in a retreating sea caused by a rising shoreline; note the succession of beds at D, viz., sandstone and shale, and at E, viz., sandstone, shale and limestone; beds a, b, c, were laid down when the sea level was at A, B, C, respectively; compare with successions in Fig. 23.

(2) **Ocean bottom oozes.**—These are deposits of fine clay, mixed with hard parts of animals and plants, the predominating constituent giving its name to the ooze. Oozes form below 6,000 feet. The distribution of the different kinds of oozes is shown in Fig. 25.

(i) **Globigerina ooze.**—This type of oceanic deposit owes its name to the abundance of shells of Globigerina which make up about 50% of the deposit. Globigerina is a minute animal living near the surface of the ocean. It secretes a chambered calcareous shell, which falls to the bottom on the death of the animal. Mixed with these shells are red clay, and the hard parts of corals, worms, sea urchins, etc. This ooze is light brown in color. It is especially widespread in the Atlantic Ocean (Fig. 26). The Chalk Cliffs of the English Channel are composed of

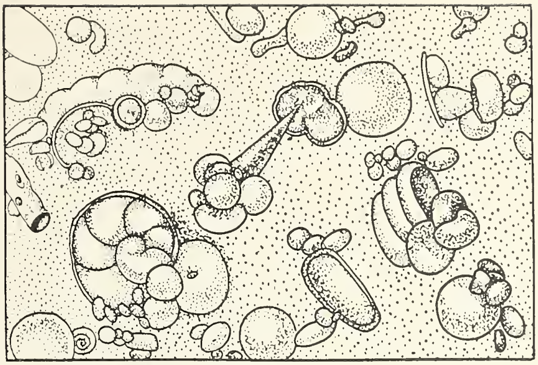

FIG. 26

Globigerina ooze; magnified approximately 25 times.

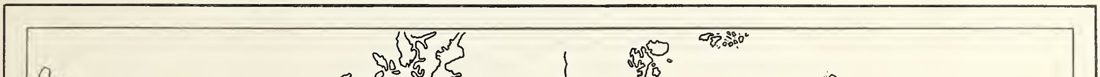

FIG. 25

DISTRIBUTION OF OOZES ON THE OCEAN BOTTOM

Areas are numbered 1 to 7. It is recommended that the student color in the various areas according to the following legend:

1. Terrigenous deposits (blue);
2. Coral sand and mud (white);
3. Radiolarian ooze (green);
4. Diatomaceous ooze (yellow);
5. Globigerina ooze (brown);
6. Red clay (red);
7. Pteropod ooze (black).

a similar ooze, but it was deposited in a shallow sea.

(ii) **Pteropod ooze.**—This is really a variety of Globigerina ooze which has a greater abundance of pteropod shells in it. Pteropods are animals which live near the surface and secrete a delicate, calcareous shell. They live only in the warmer seas; therefore this ooze is found only in the tropical and subtropical regions.

(iii) **Diatom ooze.**—Diatoms are a low form of plant life which live near the surface. They are very small, disc-shaped, and develop a skeleton of silica. Their skeletons accumulate at the bottom and may become relatively abundant. Diatom ooze is found chiefly in the Antarctic seas.

(iv) **Radiolarian ooze.**—Radiolaria are animals, microscopic in size, that also live near the surface. They develop skeletons of silica; these collect at the bottom. They are found with red clays. Calcareous shells are lacking, having dissolved before reaching the bottom. This ooze is found in the Pacific and Indian Oceans.

(3) **Red clay.**—This is the most characteristic and widespread of all deep-sea deposits. The color varies from a brick red to a chocolate brown, and is due to the presence of iron. Red clay covers about one-third of the ocean bottom, and is most abundant in the Pacific Ocean. Calcareous and siliceous skeletons may be present, along with volcanic dust (more or less decomposed), pumice, earbones of whales, sharks' teeth, etc. Red clays grade into the type of oozes mentioned above. Red clay originated from decomposed volcanic dust and pumice, which settled to the bottom of the ocean.

As a rule, in oozes, calcareous shells predominate at a depth from 6,000 to 12,000 feet, siliceous remains from 12,000 to 18,000 feet, and red clay over 18,000 feet.

(c) **Continental shelf and slope.**—The continental shelf may be regarded as a submerged part of the continent. On the average it is about fifty miles wide, and here is found most of the ocean life. The shallower seas such as Hudson Bay and North Sea are on continental shelves. The continental slopes connect the continental shelves and the abyssal plain. The continental slope has the steepest gradient, but, even at that, this gradient is no greater than that of our roads. (See Fig. 21).

20. The Ocean Water: (a) **Composition.**—All natural substances are more or less soluble in water, and as a result, pure water is never found in nature. Rain dissolves gases from the atmosphere; one of these, carbon dioxide, increases the solvent power of water. As water flows over soil and rock, salts are taken into solution and carried to the ocean. Here these salts accumulate, for only pure water is evaporated. Thus the saltness of the ocean is ever increasing. Sea-water contains 3.5% of salts, i.e., in every ton of sea water there are 70 pounds of salts. Of these salts ordinary salt makes up the greater part.

TABLE OF THE COMPOSITION OF SEA-SALTS

Salt—	Percentage of Total Salts	Tons per Cubic Mile of Sea Water
Sodium chloride (common salt)	77.7	131,526,080
Magnesium chloride	10.8	18,399,360
Magnesium sulphate	4.7	8,012,480
Calcium sulphate	3.6	6,089,440
Potassium sulphate	2.5	4,169,760
Calcium carbonate	0.3	583,520
Magnesium bromide	0.2	367.360

Despite the small percentage of calcium carbonate (or lime), it is a very important constituent of sea water, for it is of this material that animals such as corals, clams and globigerina build their shells and skeletons. Traces of many other substances such as gold, silver and copper are found in sea water.

(b) **Density and pressure.**—The density of sea-water varies from 1.025 gm. per c.c. near the surface to 1.028 gm. per c.c. at the bottom. This increase in density is due to an increase in salinity (saltness) and to a decrease in temperature, for water contracts on cooling and therefore becomes heavier. Ocean currents are caused chiefly by this difference in density. Sea water freezes about 28° F. and has its maximum density at this point. This is not true for fresh water, which freezes at 32° F., and has its maximum density about 39° F.

A column of sea-water 33 feet high and one square inch in cross-sectional area weighs about 15 pounds, or we can say that it exerts a pressure of one atmosphere. Thus, for every increase of 33 feet in depth, pressure increases 15 pounds. At a depth of 100 feet the pressure would be over 45 pounds per square inch. At great depths the pressure is enormous. In a certain experiment sealed glass tubes were wrapped in cloth and lowered to great depths, and on withdrawal they were found to be crushed to a white powder by the sudden "implosion" of the walls due to pressure.

(c) **Temperature.**—Except in the icy regions of the north and south, the temperature of the ocean decreases with depth. The following are mean temperatures at various depths:

0 feet	68° F.
600 feet	60° F.
1,200 feet	50° F.
1,800 feet	44° F.
2,400 feet	42° F.
3,000 feet	41° F.

Below 3,000 feet the fall in temperature is not so rapid (which is suggested by the table). At 13,000 feet the temperature is 35° F. The lowest temperature on record is 26° F., taken off the coast of Nova Scotia, and the highest temperature, 96° F., was recorded in the Persian Gulf.

Thus it is seen that extremes of temperature in the ocean are not nearly so great as on land, the maximum being only 70° F. in the ocean, as against over 220° on land.

In shallow seas the temperature at the bottom might not be so low as indicated in the table.

21. **Movements of the Ocean Waters:** (a) **Wind waves.**—The friction of the air at the surface of the water causes the water to move in the direction of the wind and also produces waves. If the winds are continuous, as in the Trade Wind Belts and other zones of regular winds, they will set up water currents. Great waves will also result by the addition of wave to wave, and by the extension of the motion of the water to greater depth.

The wind moves most rapidly, the waves next, while the current lags behind. The speed of waves may vary from 20 to 60 miles an hour. In waves the motion is carried on, but not the water itself. An illustration of this is furnished when one gives a quick shake to one end of a rope; a wave will be produced which travels down the rope. The motion, or we might say, energy, is transmitted along the rope. As the wave advances, the particles of water undergo a circular motion—a motion which sometimes extends to a depth of 600 feet. These are oscillatory waves.

The higher part of the wave is called the **crest,** and the lower part the **trough.** Crests and troughs are roughly parallel. The wave length, that is, the distance in a straight line from one crest to the next, is usually not over 600 feet, and for most which reach the coast it is under 25 feet. The height of a wave is not so great as is generally imagined, waves 20 feet from trough to crest being very high, and those 40 to 50 feet high very unusual.

The movement of the ocean once started will extend beyond the region of the wind, even for several hundred miles. These waves, extending beyond the reach of the wind but owing their origin to it, are regular in shape and are called **ground swell** or **rollers.** The surface of the ocean is seldom free from these waves.

When waves approach shallow water, the circular motion of the water particles is interfered with by friction along the bottom and the crest topples forward and rushes up the beach. Such a wave is called a **breaker;** a succession of them forms **surf** or **waves of translation.** After being thrown on the beach, this water runs back swiftly along the bottom. It is then known as the **undertow.**

(b) **Other waves.—Earthquake water waves** or **tsunamis** are produced by an earthquake or volcanic explosion on the sea-floor. The water of the ocean from bottom to top is affected, and the wave takes the form of a low swell, which may travel across the ocean. If such waves originate near the coast, they may increase in height on passing into shallow water, and rush upon the land with great destruction of life and property. They fortunately are rare.

The fall of ice from tidal glaciers (i.e., glaciers which reach the sea), produces **iceberg waves,** which are only of local importance. They are common in the fiords of Alaska and Greenland, where they form powerful breakers on reaching the shore.

A violent wind at sea may set up waves of great destructiveness. The wind producing these **hurricane waves** move in a whirl, the centre of which often attains a velocity of 60 to 100 miles an hour, although the hurricane itself moves forward as slowly as 8 to 12 miles an hour. Hurricanes originate in the tropics. In the North Pacific they are called **typhoons.** West Indian hurricanes originate near the West Indies, move westward into the Gulf of Mexico, then swing north-eastward across Eastern United States.

(c) **Tides.**—There are three factors which enter into the formation of tides. These are: (1) the attraction of the moon for the earth, (2) the attraction of the sun for the earth, (3) the rotation of the earth.

The ocean, being fluid, yields to the attraction of the sun and moon, and on the sides nearest to them, rises in the form of broad swells. At the same time, other swells form on the opposite sides. Between these broad swells are broad

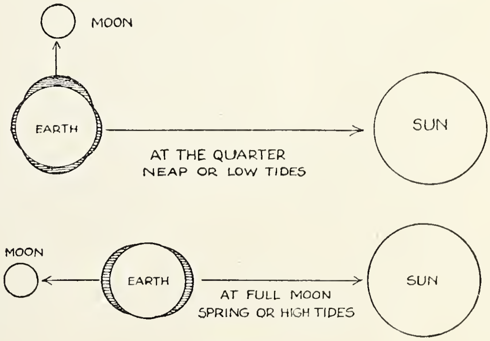

FIG. 27

Relative positions of sun, moon and earth for neap and spring tides depressions or troughs. The swell produced by the moon is a two- or three-foot rise in the ocean level on oceanic islands; but that caused by the sun is much less, as the sun's attraction is less. (Fig. 27). Thus, as the moon rotates about the earth, the broad swells or tides follow it, one tide on the side of the earth nearest it, and the other on the opposite side; and if the earth did not rotate, there would be only two tides per month. But as the earth does rotate, taking 24 hours for each rotation, every ocean on the earth's surface has two tides in a little over 24 hours, i.e., the high tides are 12 hours and 26 minutes apart. The sun also produces two tides per day.

The highest reach of the water during a day is called **high tide,** the lowest reach **low** or **ebb tide.** (Fig. 27). The time interval between high and low is 6 hours and 13 minutes.

As noted before, the rise in the level of the water in mid-ocean is only two or three feet, but when the tide enters a bay which has a wide mouth and which narrows gradually, the rise may be considerably more, on account of the bay becoming narrower and the water shallower. Ordinarily tides move very slowly, but in the Bay of Fundy, the rise varies from 37 to 53 feet. In and out of this bay the water goes with a rush, producing what is known as a **tidal bore.** Tidal bores also enter rivers, such as the Severn and the Seine.

As stated before, the sun also produces tides, but these are much smaller than those produced by the moon. As would be expected, a higher or a lower tide would be produced when the lunar and solar tides coincide. These are **spring tides,** and occur twice a month (at new and full moon) when the sun, moon and earth are in a straight line. At spring tide, high tide is highest, and low tide is lowest. A week later comes the **neap tides,** when the high water stage is least high, and the low water stage least low. These are produced when the sun and moon form a right angle with the earth. Here the solar and lunar tides are operating in opposition to each other. (See Fig. 27).

The time intervals between tides are always the same, but owing to the interference of lands, the time of high or low tides in one region is not necessarily the same as that in a neighboring region. As it is an advantage and even a necessity for mariners to know the time of high and low tide, every port has a table drawn up showing these times. These **tide tables** also show the amount of rise and fall of the tide, for some channels can be entered only at high tide.

It has been noted above that the time of a tide in one place might not be the same as the time of the same tide in a neighboring place. Thus it sometimes happens that the tide may be high in one bay, and low in an adjoining one. Therefore if the two bays happen to be connected by a strait, a current of water will flow from one bay to the other. The same result is produced if high tide in one bay is higher than high tide in the adjoining bay. These **tidal currents** or **tidal races** sometimes interfere with navigation.

Along the coasts, tides and tidal currents are of great importance, but in the open ocean they are of little account. They are important to coastal cities for removing sewage and garbage. Tides and tidal currents carry sediment about, depositing it in waters which are not so disturbed and where it may ultimately form rock. Sometimes this sediment is deposited in harbours, from which it has to be removed by dredging or by other means to prevent the harbour from being blocked up. Tides, at certain times, make channels navigable. They represent a great source of energy, of which man may some day make direct use.

(d) **Ocean Currents:**

(1) **Causes of ocean currents.** — By wind, waves and tides, water is moved only comparatively short distances, but by ocean currents water is transferred for great distances. The circulation of ocean water is very complex, and is due to a number of causes, chief of which are:

(i) A difference in density owing to a difference in temperature.

(ii) The drift of water before prevailing winds.

The low temperature of the water of the ocean bottom is due to the flow of the colder (and therefore denser) waters of the polar regions toward the equator. This slow movement along the bottom sets up a surface circulation from the equator toward the poles. This circulation also explains how the animals of the ocean depths receive oxygen. Steady winds tend to pile up water in one place, thereby causing water to flow toward the lowered level. These are wind drift currents, and are found where there are steady winds.

(2) **Principal ocean currents.** — The Trade Winds, blowing from the northeast and southeast cause a drift of water westwards along the equator. This is the Equatorial Drift. This Drift divides at the South American coast, part moving northwards, and part southwards. The two currents eventually swing eastwards and again come under the influence of the Trade Winds, the whole movement producing the **North Atlantic** and the **South Atlantic Eddies.** In the Pacific Ocean, the **North Pacific** and the **South Pacific Eddies** are formed in a similar manner.

In the centre of the North Atlantic Eddy, the water is quiet, and here large masses of floating seaweed or Sargassum accumulate; hence it is called the **Sargasso Sea.**

Part of the Equatorial Drift enters the Gulf of Mexico by way of the Caribbean Sea. Here these waters are warmed still further. The level of the water in the Gulf is raised by this indrift, by expansion due to warming and also by rainfall and inflowing streams. The Gulf water thus raised to this higher level then flows out through the Strait of Florida into the Atlantic. Here this current, now called the Gulf Stream, has a width of about 50 miles, and a depth of about 2,000 feet. Northeast of the Strait of Florida, the Gulf Stream broadens, and its velocity decreases. It is now joined by part of the North Atlantic Eddy, and comes into the belt of west winds, which drive it across the Atlantic to Northwestern Europe. It has lost its identity as the Gulf Stream and is now known as the **North Atlantic West Wind Drift.**

Between Antartica and the southern tips of South America, Africa and Australia, there is mostly water, across which west winds sweep. These winds set up a current, the **Southern West Wind Drift,** in which the surface water drifts eastward. A similar current is set up in the North Pacific Ocean. These are the Pacific Eddies.

The Japan Current is similar to the Gulf Stream in its temperature and its behaviour. It originates between the East Indies and the Philippine Islands and the Asiatic Coast. It passes into the North Pacific, where it is driven eastwards toward the North American Coast by the west wind drift.

The Labrador Current originates in the cold waters north of North America. This current of cold water, bearing icebergs, passes southwards along Labrador, Newfoundland and the New England States as far as Cape Cod. Here it turns off shore and sinks, thereby becoming lost as a current. The principal ocean currents of the world are shown in Fig. 28.

22. **Effects of Ocean Currents.**—Ocean currents are of the greatest importance to marine plants and animals. They influence the distribution of life by modifying temperature, by transporting marine food, and by supplying oxygen.

The effect on climate is well known. The temperature of winds is affected by the water over which they blow. Labrador and the British Isles are in the same latitudes, but Labrador is a bleak barren country on account of the cold Labrador Current, while the West Wind Drift makes the British Isles an agricultural region. The heat of the tropics is carried up to even the temperate zones by ocean currents.

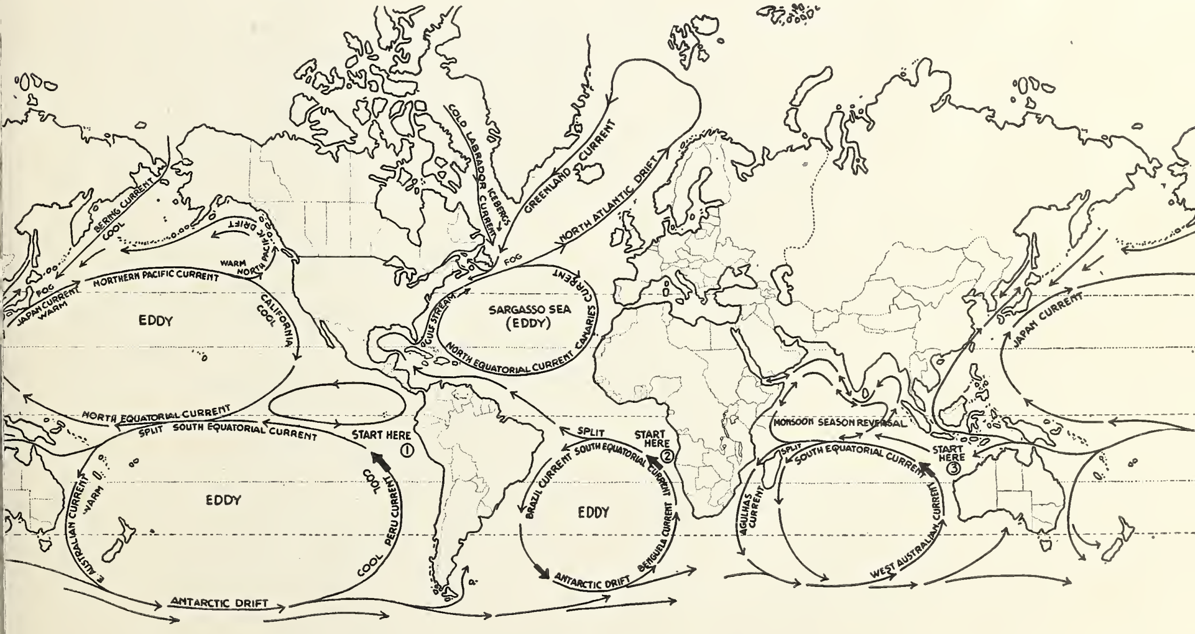

FIG. 28
OCEAN CURRENTS OF THE WORLD

Ocean currents aid or impede the progress of vessels according to the direction in which the vessels are going. When sailing vessels were in common use, ocean currents were of even greater importance.

Winds blowing over water become moisture-laden, and if these meet colder winds, moisture condenses, giving rise to fog. One of the foggiest places in the world is east of Newfoundland, where the warm winds of the West Wind Drift meet the cold winds blowing off the Labrador Current. Seldom is this region free from fog.

Currents flowing from the polar regions carry icebergs and ice floes. The Labrador Current brings down icebergs which are a menace to navigation. In the southern regions icebergs are seldom met with north of 45° south latitude. Currents in the Arctic Ocean cause ice-floes to drift about, generally westwards.

23. **Ice in the Ocean.**—Icebergs in the ocean are masses of ice which have been broken off from glaciers which reach the sea. (Fig. 88). These glaciers may be at sea level and push the ice into the water, or they may be above sea level and drop the ice over a cliff into the water. In the North Atlantic Ocean the source of icebergs is the Greenland ice sheet. As the icebergs drift southwards they slowly melt; some get as far south as the waters south of Newfoundland before melting. It was one of these icebergs that the Titanic struck in 1912, sinking, and causing the loss of 1,517 lives. That tragedy led to the establishment of the ice patrol. Since then not one life has been lost from this cause.

The shores of Ross Sea in the Antarctica are fringed with a glacier over 500 miles long and 50 to 280 feet high. This glacier is fed by numerous other glaciers. Huge blocks of this ice break off and drift northwards. Some of these are more than one square mile in area. Scott observed one which was about five miles square.

In latitudes where the temperature is low enough, ice forms on the sea. This **sea ice** is from six to ten feet thick. It is drifted about by ocean currents and broken up into ice floes. Some of these floes are carried southwards from the Arctic Ocean by the Labrador Current.

24. **Coral Reefs.**—A coral is a very small, simply organized animal which lives in a calcareous home which it builds for itself from lime taken from the sea water. These creatures live in colonies, and as a result build up masses of limestone structures having a variety of branching shapes. They can live only in warm, salt water, not more than 120 feet deep, and therefore are found only on the warmer ocean currents. The structures they build rest on the bottom, and may reach to the surface of the ocean. When they do, they are known as **coral reefs.** These reefs are common on the east coasts of Australia, Africa and Central America.

Whenever a coral reef parallels a shore for any distance, it is known as a **fringing reef.** Between this reef and the shore there is a protected shallow lagoon. When the reef forms at a considerable distance from the shore, it is called a **barrier reef.** The greatest of all reefs is the Great Barrier Reef, off the eastern coast of Australia. It is about 1,250 miles long, and from 19 to 90 miles wide. Circular reefs are found in the Indian and Pacific Oceans, and are known as **atolls.** (Fig. 29). Their circular shape is due to their being built up from a submarine island or extinct volcano. These reefs have a shallow lagoon in the centre.

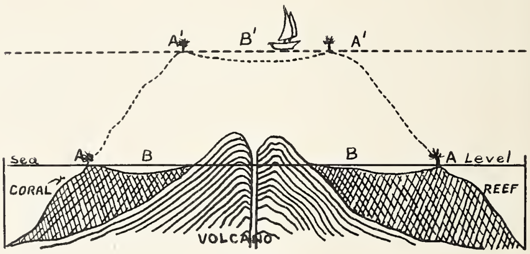

FIG. 29

Formation of an atoll: the volcano is slowly sinking, and the growth of corals keeps pace with the subsidence so that it is always encircled by a shallow lagoon B and the coral reef A; in time, only the reef A^1, more or less circular in shape and enclosing the lagoon B^1, projects above the waves.

Coral reefs are not composed entirely of coral and the remains of coral animals. They contain also the remains of other marine animals and lime-secreting seaweeds.

* * *

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Questions:

1. (a) How much of the earth's crust is covered with water?
   (b) Has the above figure always been the same? Discuss briefly.
   (c) What is the average depth of the ocean?
2. Give five reasons for the importance of the ocean to mankind.

3. (a) What is oceanography?
   (b) What studies does it include?
   (c) What is the most famous oceanographic expedition?

4. (a) Describe the plumb-line method of sounding the ocean.
   (b) Describe the method of sounding the ocean using the sonic depth finder.
   (c) The echo of a sound wave was heard 8½ seconds after the sound was made. What is the depth of the ocean at that point?

5. (a) For what purpose are trawls and dredges used?
   (b) How does a trawl differ from a dredge?

6. (a) What is the purpose of the water bottle?
   (b) Describe its operation.

7. (a) Why are the thermometers used in oceanography of a strong construction?
   (b) Describe each of the two types of thermometer.

8. (a) Describe briefly the use and operation of the core-sounding apparatus.
   (b) What is the greatest depth at which it has been used?
   (c) What are two other methods that have been used to secure samples of the ocean bottom at great depths?
   (d) Of what value are the samples thus secured?

9. (a) Give two important features of the ocean floor.
   (b) Name the four regions of the sea floor and their approximate depths.
   (c) Where is the greatest depth? How deep is it?

10. (a) Make a diagram showing the sedimentary deposits of the continental shelf.
    (b) What is the source of these sediments?
    (c) What four different agents have transported them to the sea?
    (d) The following strata were found at one place (descending order): Limestone, shale, and sandstone. Was the land sinking or rising as they were being deposited?
    (e) What is the significance of the following succession of strata (in descending order): ss., sh., ls., sh., ss.?

11. (a) What is an ooze? Where is it found?
    (b) Describe briefly each of the four kinds of ooze, and also red clay.
    (c) Colour in Fig. 25, Page 25 in the suggested manner.
    (d) Why are calcareous shells generally lacking in red clay?

12. Give four important features of the continental shelf.

13. (a) Why is pure water never found in nature?
    (b) What is the source of the salt in the ocean?
    (c) Is the amount of salt in the ocean increasing or decreasing? Explain.
    (d) How many pounds of common salt are there in one ton of sea water?
    (e) What is the importance of calcium carbonate (lime) in sea water?

14. (a) What is the density of pure water? of sea water?
    (b) Give two reasons why this density of ocean water increases with depth.
    (c) What is the freezing-point of fresh water? of sea water?
    (d) At what rate does water pressure increase with depth?
    (e) Calculate the water pressure in pounds per square inch at a depth of 495 feet.
    (f) Draw a graph to show how the temperature decreases from the surface to a depth of 3,000 feet.
    (g) Estimate the temperature at a depth of 1,000 feet.

15. (a) What causes wind waves?
    (b) What is their speed and size?
    (c) Define: crest, trough, ground swell, breaker, surf, undertow.

16. Explain briefly the causes and importance of tsunamis, iceberg waves, and hurricane waves.

17. (a) What three factors are concerned in the formation of tides?
    (b) Why has each ocean two tides a day?
    (c) What is high tide? low tide? What is the time interval between them?
    (d) How is a tidal bore produced?
    (e) Draw diagrams showing spring tide and neap tide, and explain each.

18. (a) What are tide tables?
    (b) Of what advantage are they?

19. (a) Explain how a tidal race or current is formed.
    (b) Give four reasons for their importance.

20. (a) Give the two chief causes for the creation of ocean currents, and briefly explain each.
    (b) Sketch a map of the world, and on it put the principal ocean currents mentioned in section 21 (d) 2, pages 28 and 29.
    (c) Give four effects of ocean currents, and explain each.

21. (a) What is the source of icebergs?
    (b) Where is the principal source of icebergs in the northern hemisphere? in the southern hemisphere?
    (c) In the northern hemisphere how far south do icebergs get before melting?
    (d) What is sea ice? How thick does it get? Why does it not get thicker?

22. (a) Draw a diagram of a coral polyp and briefly describe it.
    (b) What living conditions do corals require?
    (c) Define: coral reef, atoll, fringing reef, barrier reef.
    (d) Describe and illustrate the formation of a coral reef (atoll).
    (e) Of what materials is a coral reef composed?

Suggested Activities:

1. Shake up a mixture of small pebbles, sand, silt, and clay in water. Allow to settle, and watch the settling process. Let the mixture stand until the water clears. Why have the largest fragments settled to the bottom and the finest fragments at the top?

2. Take about one cubic inch of mud and divide it into two equal parts. Put each part into a large test tube; to one add water until the tube is half full, and to the other add an equal quantity of salt water. Shake each thoroughly at the same time; then set in a rack and see which mixture clears first. This experiment is designed to account for the clarity of sea water along the coasts, and especially near the mouths of rivers.

3. The transportation of sediments by streams into lakes and oceans can be demonstrated as follows: Bend a piece of tin into the shape of a trough, and place one end under a tap and let the other end dip into a pan of water. Place in the trough below the tap a small quantity of loose soil obtained from the school yard. Allow a trickle of water to fall on the pile, and run at a low angle into the pan. Note that the size of the particles in the pan becomes smaller with greater distance from the mouth of the trough. The building of a delta can be studied if the materials are replenished when necessary. Powdered coal may be used in alternate lots of the mud in order to bring out stratification better. When the experiment is completed, draw the water from the pan, and cut the deposit into two so as to expose the stratification. Vary the amount of water coming from the tap, and also the slope of the trough in order to get different results.

4. After a rainstorm find a place in the gutter where the water has run down it or into it. Note the size of the tiny fragments that make up the tiny delta, and the order in which the fragments were dropped, the larger being dropped first, then the smaller, etc. The same feature can be noted on a gravel bar in a river or creek.

5. Weight a test tube with sand in order to enable it to remain upright in water. Put it in fresh water, and mark the depth to which it sinks by placing a rubber band around it at that point. Add salt to the water, stir, and then note the distance that the test tube sinks in the brine. Why does the tube ride higher in the brine than in fresh water? In a similar manner note the difference using hot and cold water. In which should it sink farther? Explain.

6. The same experiment as No. 5 may be done using a graduate or overflow can. Will a block of ice sink farther in salt water than in fresh water? Will it sink farther in cold water than in warm water? Will an iceberg ride higher in the water as it drifts towards the equator? Explain.

7. Place water in a pan to a depth of about three inches, and allow to stand over night so that the water is warmed to room temperature. Support two thermometers in the water at one end, one to take the temperature at the surface, and the other to take the temperature at the bottom. Place in the water at the other end to the thermometers a chunk of ice. Read the temperatures every few minutes, and note that the water is cold at the bottom of the pan. A convection current has been set up—a current comparable to the Greenland or Labrador current. A few drops of ink placed in the water will show the direction of flow.

8. Secure a piece of coral and note carefully the branching structure.

CHAPTER IV

THE ROCK CRUST OR LITHOSPHERE

25. **General Features.**—The terms **rock crust, earth's crust,** and **lithosphere** are names for the rocky layer of the earth, the greater part of which is covered by the hydrosphere. The terms rock crust and earth's crust are somewhat misleading as they give the impression that the interior of the earth is in a liquid state; but such is not the case, for observations have shown it to be more rigid than the finest steel. The lithosphere is estimated to be at least 75 miles thick. (Fig. 39).

Many facts have been learned about the lithosphere from the rocks exposed at the surface. Mountain-building movements have shoved many thousands of feet of rocks above the general level of the land, thus exposing the deeper rocks to view. Besides mountainous areas, a very good place to study rocks is often to be found along a river or stream where the water carves its bed deeper and deeper into the strata. Here the rocks are exposed in the banks, especially in cut banks (Fig. 33). Valleys also sometimes supply information regarding rocks. Man learns much, too, about the lithosphere in digging mines and canals, in driving tunnels, and in quarrying rocks. Diamond-drilling provides another means of studying the lithosphere. This is a method of prospecting in which a small hole, from one to two inches in diameter, is bored into the rock. The extracted cutting, or core as it is called, may then be examined for valuable minerals. In drilling for oil, drillers take samples of the strata at regular intervals (maybe every five or 10 feet), and these are examined and recorded. Our province maintains a staff of highly trained men to examine the rocks obtained from oil-wells, who from these rocks can give an accurate estimate of the distance to the prospective oil-bearing horizon.

26. **Mantle Rock and Bed Rock.**—The mantle rock or soil mantle consists of unconsolidated or loose particles which cover most of the land. It is composed of rocks and rock particles derived from bed rocks, mixed with vegetable matter. It may vary in thickness from nothing at all to many feet. The top soil usually is a mixture of sand, clay, and humus (vegetable matter); under this is the subsoil, which may be gravel, sand, clay, or loam (a soil rich in humus).

Variation in the amounts of sand, clay, and humus in the soil determines its kind. Thus a sandy soil is one which is composed largely of coarser mineral and rock particles. In classifying soils according to composition in this way agriculturists distinguish three main types: **sandy, clay,** and **loam soils.**

Soils are also classified according to place where found: **residual** (or **sedentary**) soils are those found where they were developed; **transported** soils are those that have been carried from the places of their formation. Residual soils were formed from the breaking down of the bed rock which formerly out-cropped where they now occur (Fig. 30), or from accumulation of vegetable matter. Transported soils have been carried to their present positions by gravity, rivers, lakes, seas, glaciers, and winds. Most of the soil in Alberta has been deposited by glaciers, that is, it is a glacial soil. Transported soils may show stratification, i.e., layers of sand, clay, gravel in any order, as seen in many river banks. Residual soils get coarser with depth, grading from soil at the surface, through sand, gravel, and boulders to bed rock underneath. Residual soils are of the same material as the bed rock; transported soils are made up of materials from different rocks.

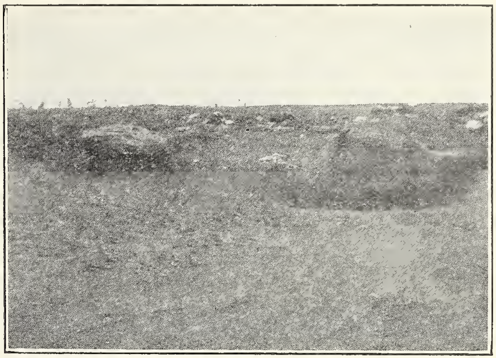

FIG. 30

Sandstone of the Edmonton formation weathering to form a residual soil, one of the few soils of this type in Alberta; no glacial drift on the surface; found near Claresholm.

Below the soil lie the hard and firm layers from which the soil has been formed. This is the **bed rock.** It has originated in the consolidation of molten rock or mantle rock, such as clay, sand, gravel, boulder clay, etc. It is exposed at the surface in some places as in the mountains, but in most places it is covered by the soil mantle or by water. Bed rock may consist of granite, sandstone, shale, limestone, etc. It is of great use to man as a source of building materials, salt, coal, iron, copper, etc.

Most rocks, as far as we know, were laid down or extruded upon the continent or continental shelves. Of the rocks of the ocean basins not much is known, but it is inferred that they are heavy rocks.

27. **Rocks of the Crust.**—Rocks are composed of a single mineral or, more often, of several minerals. A mineral is made up of one or more

simple substances or elements like iron, calcium, carbon, silicon, oxygen. Thus the union of silicon and oxygen forms the very common mineral quartz, and the union of calcium, carbon and oxygen forms calcium carbonate, which is the chief constituent of limestone. Rocks are classified in three great groups: (1) Igneous; (2) Sedimentary; (3) Metamorphic.

(1) **Igneous rocks.**—These rocks result from the cooling of molten rocks either at the earth's surface or not far beneath it. Rocks, like lava, were erupted upon the earth's surface and are called extruded rocks. Other molten rocks which were irrupted into the earth's crust are called intruded rocks. Intruded rocks, which did not reach the earth's surface at the time of their irruption, might be exposed later by erosion of the overlying rocks.

Extrusive rocks are those given out by volcanoes, and consist of large and small fragments which have been blown out, and lava which has been poured out. One type of lava is **basalt.** Basalt is a glassy or fine-grained, dense rock, and it is sometimes cellular, i.e., it may have cavities in it. When molten it flows easily, and the stream may extend for several miles.

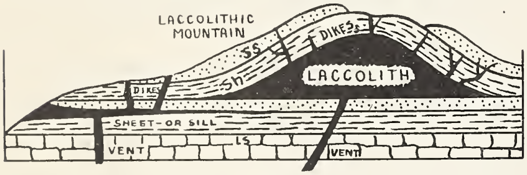

FIG. 31

Section showing dikes, sill and laccolith; the last has arched the strata to form a laccolithic mountain.

Intruded rock forms various structures. If it has penetrated between approximately horizontal strata (rock layers) to form a thin layer, it is called a **sheet** or sill (Fig. 31). If in pressing upward it has formed cracks in the overlying rocks and then filled these cracks, these more or less vertical walls of rock are called **dikes.** They may be from a few inches to many feet thick and tend to occur in swarms. The type of rock usually found in sills and dikes is dark-coloured and fine-grained, and is usually called **diabase.**

A **laccolith** is an intrusion of igneous rock into stratified rock, arching up the strata into the form of a circular or elliptical dome (Fig. 31).

Batholiths are the largest of the intruded bodies of rock. They have come from great depths, having risen by melting the rocks above them. They form the roots of mountains, and are only exposed by erosion. They are sometimes hundreds of miles in length and have an unknown depth. In shape they are irregular domes (Fig. 32). If part of a dome exposed at the surface is more or less circular in shape, it is called a **boss.** Granite is the rock type most commonly found in batholiths. It is a coarse-grained rock composed largely of quartz and felspar, and is generally pink or grey in color. Ore deposits are often associated with batholiths.

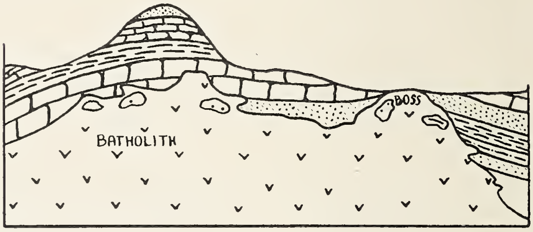

FIG. 32

Section of a batholith and boss; masses of the country (original) rock have not been dissolved and remain in the igneous rock as inclusions.

(2) **Sedimentary rocks.**—The original source of these rocks is largely igneous rocks, which by their disintegration supply boulders, gravel, sand, clay and soluble compounds. These materials, large and small, having been transported by gravity, rivers, waves, ocean currents, winds or glaciers, are consolidated to form

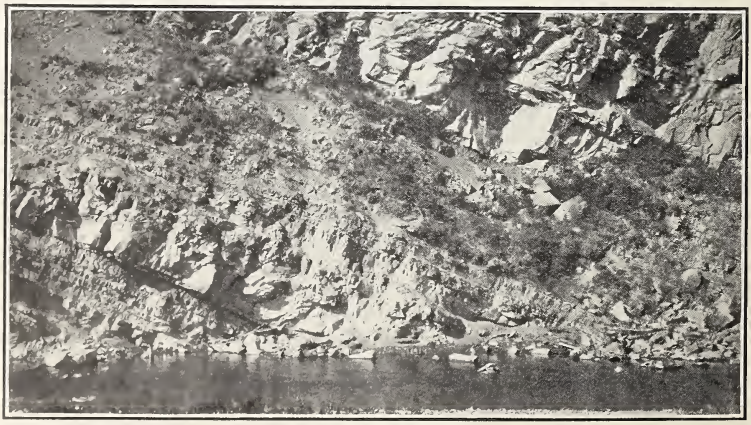

FIG. 33

Sandstone strata at the base of the Edmonton formation exposed along the Jumpingpound Creek near Cochrane.

bed rock again. Such bed rock forms in layers or beds called **strata** (singular statum), which may vary in thickness from a fraction of an inch to many feet. (Fig. 33). One stratum is separated from another by a different type of sediment; for example, strata of sandstone may be separated by thin layers of shale or fine sand or carbonaceous (plant) matter. Consolidation of the loose particles may have resulted from pressure of the overlying beds or of earth movement such as mountain building, or it may have come about by the deposition of some cementing material such as calcium carbonate, iron oxide, or silica around each particle, thus binding the whole mass together. Sedimentary rocks are classed in three groups: mechanically formed, chemically formed and organic.

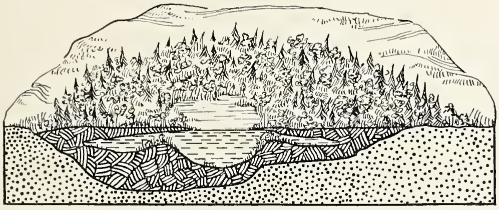

FIG. 34

A lake filling in gradually from the edges with vegetable matter to form a bed of coal on being covered with sediment.

(a) **Mechanically formed.**—Most sedimentary rocks have been laid down by water, and so most of the particles in a sedimentary rock will be of about the same size, as water assorts the particles as to size. A strong current is capable of carrying large particles, and of rolling boulders along the bottom. But as the strength of the current diminishes, the larger particles of rock are dropped. For example, when a river empties into the sea, the coarser sand is deposited at the mouth, while the finer mud may be carried some distance before it settles to the bottom. This is also true of wave action along coasts where materials are carried out by undertow, and deposited on the continental shelf.

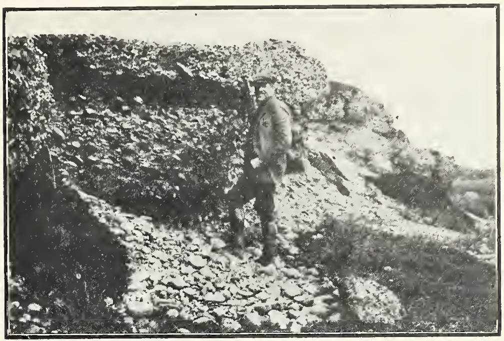

FIG. 36

Cypress Hills conglomerate of Oligocene age; it consists of water-worn stones held together by a calcareous cement; on Cypress Hills in southeastern Alberta.

Rocks laid down by water are conglomerates, sandstone, and shales. **Conglomerate** is composed mostly of rounded pebbles, fairly well assorted in size, with sand filling the spaces between them (Fig. 36). Conglomerates composed of boulders are also found. **Sandstone** is composed of quartz sand grains cemented together. The yellow, red or brown coloration of sandstone is due to iron oxide cement. The McMurray bituminous sand of Northern Alberta is a sandstone having asphalt as the cementing material. **Shale** is formed from clay and mud from which the water has been squeezed by pressure.

Sandstones formed from wind-blown materials are known, but are not common. Glaciers transport unassorted boulders, pebbles, sand and clay which sometimes form a conglomerate called **tillite.** Conglomerate may also be formed by the cementing of large rock fragments which have collected at the bases of moun-

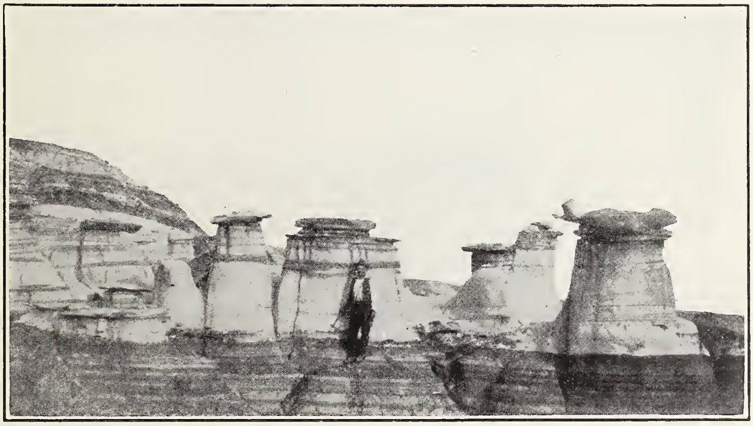

FIG. 35

Wind-formed "hoodoos" of bentonitic sandstone at the base of the Edmonton formation. Note the thin capping rock. The hoodoos rest on dark marine shales of the Bearpaw formation. The actual contact between these two formations is shown in the picture. Near Rosedale, along Red Deer River.

tains. Here the transporting agent was gravity.

(b) **Chemically formed rocks.** — The compounds dissolved from the rocks and carried in solution may be deposited by chemical action to form rock. The most common rock formed in this way is **limestone.** Lime (calcium carbonate) may be precipitated from water directly by chemical action, or indirectly by some animals and plants. These organisms extract calcium compounds from the water to build their shells or skeletons, and, on dying, their remains collect at the bottom, sometimes forming thick beds. Thus the hard parts of corals, clams, oysters and brachiopods are common in limestone, even to the extent of making up the whole bed. While alive, these plants and animals assist in the chemical precipitation of calcium carbonate, so that their hard parts are nearly always enclosed in chemically precipitated calcium carbonate.

As water percolates through limestone beds it dissolves some of the rock, thereby becoming rich in calcium carbonate. This substance may be deposited if the water drips from the roof of a cave. Some of the water evaporates, depositing lime and in time it builds an icicle-shaped structure called a **stalactite.** At the same time the water dripping on to the floor of the cave builds up a similar structure. This is a **stalagmite,** and it may in time meet the stalactite above, forming a column (Fig. 41).

Deposits of salts and gypsum are formed by the evaporation of water in arms of the sea which are cut off from the main body, and also by the evaporation of water from lakes which have no outlet. As the water in these evaporates, the salts in solution are deposited on the bottom, and will be preserved if they are covered with a protective layer of sand or clay or other material. The salt deposits of Stassfurt in Germany, and of McMurray in Alberta, etc., originated in this way. Deposition of salts is going on at the present time in the Great Salt Lake of Utah, in Kara Bugas Gulf of the Caspian Sea (Fig. 60), and in other places. Common salt and gypsum and other salts are deposited in this way, and are usually found associated.

(c) **Organic rocks.**—The two principal rocks in this group are limestone and coal. The part played by animals and plants in the formation of limestone has already been considered under chemically formed rocks. (See above). Beds of shells of clams, oysters, snails, etc., are fairly common in rocks.

Coal is formed from plant remains such as trees, bushes, moss, ferns, etc. These plant remains may have accumulated in lakes and swamps. These materials collect on the edges of the lake, and fill them in gradually. Fig. 34 shows a lake in the process of filling up with organic material. This accumulated organic material is **peat.** On being covered with sand, clay or other material, the peat is compacted, and some of the water and gases are driven out by the pressure. Thus **lignite,** a low grade of coal, is formed. With further application of pressure caused by greater folding of the strata more water and gases are driven off, and **bituminous** coal is produced. Still more pressure produces **anthracite,** which is the richest in carbon and the highest grade of coal. Anthracite is about 90% carbon. In Alberta the coal of the prairies is lignite, but in the foothills and mountains, where mountain-building movements have supplied the pressure, the coal grades into the bituminous variety. A further step produces **graphite,** a form of pure carbon, which may be formed from anthracite. The "lead" in a pencil is graphite. As swamps are most prevalent along sea coasts, it is supposed that much of our coal was formed from vegetation which grew and accumulated in coastal and river swamps. It is readily seen that peat grades into lignite, lignite into bituminous coal, and bituminous coal into anthracite, according to the age of the deposit and the amount of pressure to which it has been subjected.

Sedimentary rocks which were laid down in the sea at the same time exhibit the following order: sandstone close to the shore, mud further out, and limestone beyond that (Fig. 22). Alternating beds of sand, stone and shale, or shale and limestone indicate a fluctuating shoreline (Figs. 23, 24). So then seams of coal alternating with sandstone and shale indicate a shoreline which rose and sank, now above sea level to form a lake or swamp, and then low enough for the accumulation of sediments. Such a succession of coal seams is common in coal fields. In the Edmonton formation along the Red Deer River near Drumheller as many as 14 seams have been counted. (Fig. 42).

(3) **Metamorphic rocks.** — These are rocks which have been altered to their present form by one or more of the agents, heat, pressure, and water. These agents may so alter a rock in composition and appearance that its original character can hardly be recognized. The rock surrounding and covering batholiths is always rock changed more or less by the intense heat and the solutions given off.

Sandstones may have the particles so welded together by pressure or so cemented together by silica as to form a hard, compact rock called **quartzite.** Quartzite is very common in gravels. Shale under pressure is metamorphosed to **slate.** New minerals are formed in this change, and these arrange themselves more or less parallel to each other, thus accounting for the ease with which slate can be split into thin sheets.

Limestone under heat and pressure changes to **marble.** In this metamorphosis the rock recrystallizes. Anthracite coal may be considered a metamorphic rock.

Schist is formed from igneous and sedimentary rocks under extremely great pressure. The original minerals in the rock may be changed to others, and these latter minerals arrange themselves in thin layers or bands, along which the rock splits fairly easily. **Gneiss** (Fig. 37) is formed in the same way as schist, but the banding is not so highly developed. Therefore the rock does not split so easily along the bands. It also exhibits a rougher surface. Both schist and gneiss are found in regions of intense pressure, as in mountainous regions or where mountains once existed.

SUMMARY OF METAMORPHISM OF SEDIMENTARY ROCKS

Unconsolidated	Consolidated	Metamorphosed
gravel	conglomerate	gneiss and schist
sand	sandstone	quartzite and schist
clay and mud	shale	slate and schist
shells and lime	limestone	marble
humus or peat	coal	anthracite

28. **Resistance of Rocks.**—All rocks originated as outlined above. As long as these rocks are subjected to the conditions under which they were formed, they will undergo little change. For example, rocks formed under water will undergo little change as long as they remain under water; but if they are raised above water, then the agents of weathering and erosion attack them, breaking them down. However, as the earth's crust is subject to slow movements which raise parts of it above the sea, then lower them beneath the sea, all rocks will ultimately be attacked by weathering and erosion. Those solid rocks which form on land, as in the case of lava, will, of course, be attacked at once. The processes of weathering and erosion are called **denudation.**

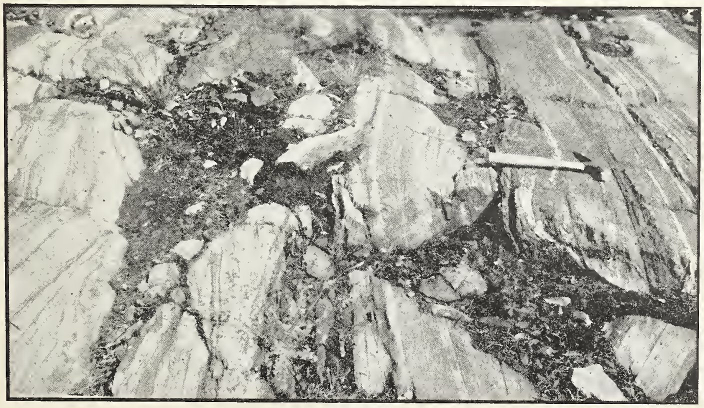

FIG. 37

Banded gneiss (Precambrian) in the Charles Lake area, northern Alberta, north of Lake Athabaska.

Weathering of rock.—This is the process of decomposition and disintegration of rock by various agents, the most important of which are percolating water, air, changes of temperature, and the action of animals and plants.

(1) **Percolating water,** that is, water which soaks into the soil to bed rock, dissolves some mineral matter from the rocks, and changes other minerals. These actions not only remove part of the rock, but weaken it so that it is more easily attacked by other weathering agents. The presence in the water of carbon dioxide, which is obtained from the air, increases its solvent power. It was noted above that stalactites and stalagmites (Fig. 41) were formed from lime dissolved in percolating water. Percolating water with its dissolved mineral substances ultimately appears as springs, which in turn feed streams, and by them reaches the sea.

(2) **Air.**—The water vapor and oxygen of the air attack certain minerals in rock, thus decomposing them. Iron compounds are easily oxidized and broken down in this way, as evidenced by the yellow, red and brownish stains on some rocks. As noted above, carbon dioxide obtained from the air increases the weathering power of percolating water. Rocks in arid regions will be little affected.

(3) **Changes in the temperature** of the air greatly increase its effectiveness as a weathering agent. The amount of expansion or contraction of any substance differs from that of any other substance when exposed to the same change in temperaature. Consequently alternate expansion and contraction of the minerals composing the rock through being heated in the day time and being cooled at night sets up stresses and strains which in time loosen them. They are then more easily attacked by percolating water and oxygen, both of which complete the work of weathering. Sometimes the heating and cooling causes thin layers of the rock to break off; this process is known as **exfoliation.** Changes in temperature are particularly effect-

ive as a weathering agent in mountainous and desert regions.

(4) **Frost.**—By freezing water which has percolated into cracks, frost splits the rock by the water's expansion. This is important in the breaking up of rock into angular fragments. It is especially active on mountain sides and peaks, accounting for the accumulation of loose rock found there.

(5) **Plants.**—The roots of plants are capable of exerting great pressure. The heaving-up of blocks of cement sidewalk by root pressure is a matter of common observation. A small root growing in a crevice will, as it grows, force the walls of the crevice farther apart. Rocks may be further broken up by this agency. Plants are especially active in this way in mountain regions or where rock is exposed at the surface. Pines growing on steep rocky slopes thrust their roots into bed rock and thus maintain a firm hold.

(6) **Animals.**—The action of burrowing animals such as gophers, earthworms, etc., will tend to further break up rock particles. The pounding of hoofs of some animals also causes a certain amount of rock disintegration. Man assists in rock disintegration by his mining, quarrying, agricultural and road-building operations.

29. **Rate of Weathering.**—The rate at which rock weathers depends on a number of factors, the most important of which are: (1) the kind of rock, (2) climate, (3) exposure, (4) steepness of the slope, (5) vegetation.

(1) **The kind of rock.**—The harder rocks, such as sandstone, quartzite, and granite, are, as a rule, more resistant to weathering than other rocks, such as shale, limestone, and coal. The former rocks are said to be durable, the latter, weak. Hence the durable rocks will cap the prominent ridges, mountain peaks, and hills, while the weak (easily eroded) rocks may form valleys. Some of the ridges of the foothills of Alberta, as at Turner Valley, are crested with durable sandstone (Fig. 38). Prominent shoulders of mountains and cliffs are formed of durable rock. The Cypress Hills in the southeastern part of the province and the Hand Hills, situated a few miles east of Drumheller, are capped by a durable conglomerate of quartzite boulders from 50 to 500 feet thick in places. This conglomerate is called the Cypress Hills formation (Fig. 36). Lava is not very durable. Some lava has sufficiently decomposed in 100 years to be fit for agriculture.

(2) **Climate** not only determines to a certain extent the rate of weathering, but also the kind of weathering. Weathering is least rapid in regions having arid (dry) climates, for there the work of water and of organisms is reduced to a minimum.

(3) **Exposure.**—Rocks which are exposed to the air will weather more rapidly than rocks which are covered with a mantle of soil. Rocks which are soil covered will be subject chiefly to the action of percolating water, whereas other rocks will be acted on by all the agents of weathering.

(4) **Steepness of the slope.**—The steepness of the slope is important in the weathering of steep hills and mountains. Down these the loosened rock fragments tumble to the bottom, thereby exposing fresh surfaces to be acted on by the agents of weathering. Where the slopes are gentle, the rock fragments will remain in place, form soil, and thus protect the underlying rocks.

(5) **Vegetation.** — Vegetation, as we have noted, is an agent of weathering; but at the same time it retards this process, the latter effect, perhaps, being greater than the former. The tangle of roots tends to hold the soil in place, and this stability retards rapid weathering. Instance are numerous of man's assisting the processes of weathering and erosion by destroying vegetation, thereby allowing the soil to be removed.

30. **Results of Weathering.**—These are many and varied, among which are: (1) influence on topography, (2) formation of soil and talus, (3) valley broadening, (4) presence of dissolved mineral substances in water, (5) landslides, (6) soil creep, (7) formation of secondary rocks.

(1) **The influence on topography.** (Topography is the configuration of the earth's surface or the relief, and includes such features as

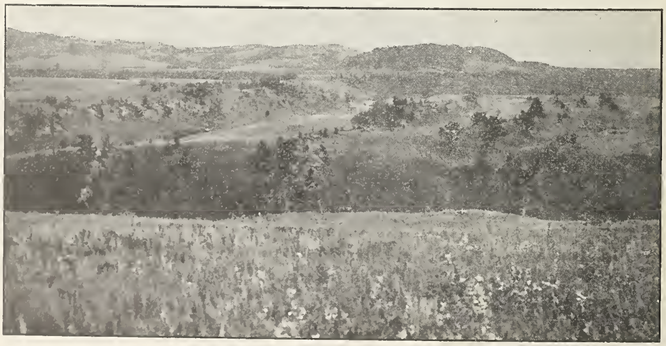

FIG. 38

Parallel rock outcrops in southwestern Alberta in the foothills and trending northwest and southeast; they form ridges and originated at the same time as the Rocky Mountains.

elevations, depressions, hills, valleys, plains, etc.)—The influence of weathering on topography has already been noted in the rate of weathering. The weak rocks are more easily sculptured into valleys and depressions, thereby causing the more durable rocks to stand out in relief as hills, ridges, etc. (Fig. 38). Dikes may stand out as ridges or hogbacks, if the igneous rock is more resistant than the country rock into which it was injected; but if it is softer, the dikes will lie at the bottom of trenches.

(2) **Formation of soil and talus.**—To us, soil is the most important product of weathering, for it makes possible life on the land by enabling plants to grow there. It is the most extensive of all products of weathering.

Talus consists of rock fragments of various sizes which have weathered loose from a steep face of a mountain or hill, and have fallen to the foot where they have accumulated. The fragments grade upwards from the largest at the bottom to the smallest at the top of the slope. Talus slopes are common in the mountains, as at Banff.

(3) **Valley broadening.** — As much of the material which forms talus slopes comes from the sides of mountains, it follows that the valleys will gradually be broadened; for as the fragments of rocks are detached, the sides of the valley will move farther apart.

(4) **Dissolved mineral substances.** — Substances dissolved out of the rocks are mostly carried to the sea; but some are deposited inland, as in the Great Salt Lake of Utah, and in the salt lakes of Saskatchewan and Alberta, and along the shores of alkali sloughs where the white crusts of salt are clearly visible. All water contains these substances in greater or less abundance. Water percolating through rock dissolves minerals which may be deposited at a lower level to form a workable ore deposit. Such is the origin of many deposits of copper, silver, etc.

(5) **Landslides.**—These are spectacular and destructive, but are fortunately uncommon. They are caused by the disintegration (due to weathering) of steep cliffs, the mighty masses of which are precipitated by the extra pressure of a high wind, or a heavy fall of snow, or by the shaking of an earthquake. One of the largest landslides in the world occurred at the town of Frank, Alberta, in 1903. Part of Turtle Mountain slid down, completely demolishing the town and killing 70 persons. In this case coal mining operations probably hastened the landslide. When the fall consists of rock and snow, it is called an avalanche.

(6) **Soil creep.**—The alternate effects of rain and drought and of heat and cold on the soil cause its particles to move slowly downhill, even on the gentlest of slopes. This action, though extremely slow, accounts in part for the greater thickness of soil at the base of a hill than on the sides. Percolating water lubricates the soil particles, thus making the soil creep more rapidly. Soil creep may exert so great a force as to cause layers of bed rock to be inclined downhill.

(7) **Formation of sedimentary rocks.** — The disintegration of rock supplies material for the agents of erosion: Water, wind, ice, lakes and oceans. This material, consisting of large or small fragments, will be deposited to form beds of sedimentary rock, as noted previously. Strata are laid down in a horizontal position, but may be found inclined at various angles. These facts are good evidence of earth movements (Figs. 6, 7, 33).

31. **Agents of Erosion.**—Weathering goes no further than the decomposition and disintegration of the rock, but erosion involves three processes: (1) removal of loose particles, or deflation; (2) transportation; (3) deposition or aggradation of rock fragments. The agents of erosion are wind, rivers, oceans, lakes, and glaciers.

Wind, as an erosive agent, operates everywhere, but is most effective along coasts and in arid regions, such as deserts. Pillars carved by the wind are shown in Fig. 35. Note the capping of the more resistant rock. Rivers and streams carry away the products of weathering, and at the same time deepen and widen their beds by means of the rock fragments which they carry. Oceans, by means of their waves, currents, and tides, attack the coasts. Lakes resemble oceans in this respect. In Fig. 61 is illustrated the effectiveness of ocean waves as an erosive agent. Glaciers are now confined to mountains and the polar regions, but at various times they have been quite extensive, covering great areas of all the continents. Glaciers are an effective agent of erosion.

Denudation, which includes both weathering and erosion, tends to reduce the earth's surface to the level of the sea. But the continued uplifts of the continents make this a never-ending task. At no time in the past has there been as much land above the sea as at the present time. The work of denudation is by no means uniform over the earth's surface. It varies with climate, slope, and the composition, structure, and attitude of the rocks.

32. **Centrosphere.**—The earth might be considered to be a huge ball made up of three concentric shells about an inner sphere. The

shells are the atmosphere, the hydrosphere, and the lithosphere; the inner sphere is called the centrosphere.

As the centrosphere is inaccessible, little is known about it; and what is known has been learned from a study of earthquake waves or has been drawn by inference. Observations made in deep borings show that the temperature of the earth increases with depth at the rate of about 1° Fahrenheit for every 100 feet. From this it is inferred that the temperature at the earth's centre may reach 200,000° to 300,000° F. At this temperature the rocks would immediately be vaporized, were it not for the enormous pressure of the overlying material.

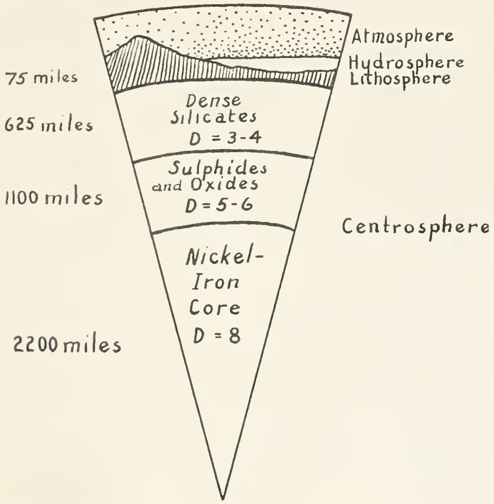

FIG. 39

Section of the earth to show its composition; note that the density increases towards the centre.

The rigidity of the earth has already been pointed out. (See page 37).

The centrosphere is made up of heavier material than the lithosphere, for the average specific gravity of the lithosphere is 2.7, while that of the whole earth is 5.6. Some scientists take the view that the rocks get heavier towards the centre of the earth, and that the very core of the earth might be composed of iron and nickel or even gold or platinum (Fig. 39). (Specific gravity is the ratio between the weight of a given volume of a substance and the weight of an equal volume of water. Thus, as iron is seven times as heavy as water, its specific gravity is 7.)

* * *

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Questions:

1. (a) What other terms are applied to the lithosphere? Are they appropriate?
   (b) What are the principal features of the lithosphere?
   (c) What is the estimated thickness of the lithosphere?
   (d) List eight different places and ways where the lithosphere is studied.

2. (a) Give the meaning of soil mantle.
   (b) Of what materials is it composed?
   (c) What are the three types of soils, classified according to composition?
   (d) What six agencies transport soils?
   (e) In what two ways do residual soils form? Make a diagram to illustrate one of these methods.
   (f) Give three ways of distinguishing a residual soil from a transported soil.

3. (a) Define bed rock. How was it formed?
   (b) What kinds of rock may be found in it?
   (c) List six materials of economic importance that might be obtained from it.
   (d) Where were most rocks laid down?
   (e) What is inferred about the rocks of the ocean basins?

4. (a) Of what are rocks composed?
   (b) What are the three main classes of rocks?
   (c) Are all minerals of value? Explain.

5. (a) What are igneous rocks?
   (b) Distinguish between erupted and irrupted rocks.
   (c) What is basalt? Is it an intrusive or extrusive rock?
   (d) Make a diagram to show a dike, sill (or sheet), and laccolith.

6. (a) What size are batholiths? What shape are they? How have they risen?
   (b) Where are they found?
   (c) What type of rock is commonly associated with batholiths?
   (d) Make a diagram of a batholith and boss.

7. (a) What is the original source of all sedimentary rock?
   (b) What sedimentary materials are formed from igneous rocks?

(c) What six agents transport sediments?
(d) In what two ways is the consolidation of sediments brought about?
(e) What are the three cements that commonly bind rock particles together?
(f) What are two sources of rock pressure?
(g) What are the three subdivisions of sedimentary rocks?

8. (a) Where are most sedimentary rocks formed?
(b) Why are most particles in a sedimentary rock about the same size?
(c) Define: conglomerate, sandstone, shale, tillite.
(d) To what is the reddish or yellowish colour of rock due?
(e) What is a stratum?

9. (a) Which is the commonest of chemically formed rocks?
(b) Give two ways by which limestone is formed.
(c) Describe briefly the formation of stalactites and stalagmites.
(d) Give two places where deposits of salt and gypsum might accumulate.
(e) What are the conditions necessary for the formation and preservation of a salt bed?
(f) What two salts are generally found associated as a result of evaporation of sea-water?
(g) Where in Alberta is McMurray? For what is it important?

10. (a) What are two common organic rocks?
(b) Draw a cross-section of a peat bog.
(c) Outline briefly the steps in the formation of coal from peat to anthracite.
(d) How do you account for the occurrence of a number of coal seams in a coal field?
(e) What is a coal field?
(f) Why is anthracite found only in mountainous regions or regions of worn-down mountains?
(g) Where did most of the peat beds form?

11. (a) What are the agents of metamorphism?
(b) Why is the rock adjacent to batholiths always altered?
(c) Define: gneiss, schist.
(d) Learn the table of metamorphic rocks on page 41; then from memory fill in the following blanks:

Unconsolidated	**Consolidated**	**Metamorphic**
	conglomerate	
sand		
		slate
shells and lime		
	coal	

12. (a) When will rocks undergo little change?
(b) Why will all rocks be ultimately attacked by denudation?
(c) What is meant by denudation?

13. (a) What is weathering?
(b) Name the six important agents of weathering.
(c) Describe briefly the work of each of these agents.

14. (a) What are the five important factors that determine the rate of weathering?
(b) Name three kinds of rock that are very resistant to weathering.
(c) Explain the part played by weak and durable rocks in the formation of valleys, hills and ridges.
(d) Is lava a durable rock? Explain.
(e) In what type of climate is weathering most rapid? least rapid?
(f) What is the relation of exposure of rocks to rate of weathering.
(g) Why does rock on a steep slope weather rapidly?
(h) Vegetation both assists and retards weathering. Explain.

15. (a) What type of rock forms valleys?
(b) What is a hogback?
(c) What product of weathering is most important to us? Why?
(d) What is talus? How is it formed?
(e) How does weathering broaden valleys?
(f) What part does weathering play in producing salt deposits?
(g) How does weathering produce ore deposits?
(h) What may have set the rocks in a landslide in motion?
(i) What causes soil to creep downhill?
(j) What kind of rock is formed from the materials of weathering?
(k) Name seven important results of weathering.
(l) Explain why sometimes anticlines occupy valleys and hills synclines.

16. (a) What processes are involved in erosion?
(b) Name the five agents of erosion.

(c) Describe the work of each of these agents.

(d) What is the tendency of denudation? Why is it a never ending task?

(e) What factors cause the work of denudation to vary at different places?

(f) In what epoch was the most land surface exposed?

17. (a) Name the four spheres or shells of which the earth is composed.

(b) How is information about the centrosphere gathered?

(c) What is the rate at which the temperature of the lithosphere increases?

(d) The deepest well in the British Empire is Okalta No. 6 in Turner Valley. What is the increase in temperature from the top to the bottom, the well being 10,200 feet deep?

(e) Give four features of the lithosphere.

(f) Make a diagram of the earth, showing its composition and the four spheres.

Suggested Activities:

1. Close examination of the bed rock should be made wherever possible. This may be done in wells, mines, quarries, road cuts, cut banks, and the banks of streams. Note especially the kind of rock. How was this rock formed? Was it formed near the shore, or farther out? Is there any change in it vertically? Is any use made of this rock locally?

2. Examine a cross-section of the soil and subsoil in a road or railway cut. Note the dark upper layers of the top soil and the lighter coloured subsoil. What causes this change in colour? Such a cross-section of the soil is known as a "soil profile."

3. How many kinds of transported soils can you find in your district? How was each identified?

4. Make a collection of rocks, and classify them as igneous, etc. Each specimen should be given a number, and a permanent record of it kept in a book provided for that purpose. The number may be placed on a small piece of paper glued to the specimen, or it can be printed on a dab of white paint placed on the rock. Information recorded should include the date of receipt, donor's name, name of specimen, where found, etc.

5. What evidence of stratification can be found in the bed rock that is exposed locally? Make a stratigraphic record of 25 or 50 feet of rock; i.e., measure the thickness of each stratum, and record the kind of rock, colour, texture, composition, included fossils, and any other noteworthy property.

6. Crush a small piece of shale in a mortar and mix with water. Note that it is like mud. Do likewise with sandstone. Dissolve a small piece of limestone (about 1 c.c.) in hydrochloric acid. What gas is evolved? What is the residue—clay or sand? Treat similarly with acid pieces of conglomerate and sandstone. If they disintegrate in the acid, the cement has been calcium carbonate (lime); if they do not disintegrate, the cement is probably silica.

7. From the succession of rock types recorded in No. 5, deduce what fluctuations have occurred in the land level at that place, i.e., how has its distance from the shore-line varied?

8. Dissolve a small piece of limestone in acid; catch some of the gas that comes off, and test it for carbon dioxide with limewater or a burning splinter.

9. If there is a coal mine in your vicinity, search the mine dump for fossil plants. Look in the shale for these remains.

10. Examine the outcrops of bed rock in your district for evidence of differential weathering of rock. Note which types of rock erode readily (comparatively), and which types are resistant. What are the principal agents of weathering and erosion that are operating on these rocks? Can you find any evidence of oxidation in these rocks? Why are some red or yellow? Look for evidence of the work of frost, plants, animals, etc., in weathering.

11. Study the effects of the resistance of rocks on topography. Why do hills and ridges stand above the general land level? What has made these areas remain higher than the valleys? They are either moraines or have a capping of resistant rock.

12. Examine the fragments of rock which have collected at the foot of a cut bank, cliff, or steep slope. Note the gradation in size from large at the bottom to small at the top.

13. Look at some soil under a microscope or powerful reading glass, and note the abundance of rock particles. What is the origin of these particles? Are you able to identify any of the minerals?

14. Search for examples of wind and water as agents of erosion. What is the origin of the dust in a dust storm? Where does it go? What work does it do as it sweeps along the ground?

15. Keep a record of the shape of the shadow of the earth on the moon in its various phases. What does this shadow tell us regarding the shape of the earth? What does it tell us regarding the rigidity of the earth?

16. Obtain a topographical map of your district from Ottawa. Where are the highest and lowest elevations? Are these elevations due to the resistant rock or deposits of glacial debris? Which are the important streams? Why do they flow in the directions that they do? Do they all flow in the same general direction? Are there any lakes? How do you account for them?

CHAPTER V

* * *

RIVERS, VALLEYS, LAKES AND SWAMPS

33. **Source of Supply of Water.** — The ultimate source of all water in rivers and lakes is precipitation, i.e., rain, snow and hail, which have condensed out of the atmosphere. The amount of precipitation varies in different parts of the earth's surface from over 400 inches in India (North of the Bay of Bengal, at the foot of the Himalaya Mountains) to almost zero in other parts of the world, as in Northern Chile, where an interval as long as eleven years without precipitation of any kind has been known.

Part of the rain which falls to the ground runs off and is known as the **immediate run-off;** another portion, the **delayed run-off,** soaks into the earth, and the third portion returns to the air by evaporation. The delayed run-off or underground supply seeps into the soil and subsoil and even into the pores and cracks in solid rock. The amount which penetrates solid rock depends on the porosity of the rock. Sandstone is one of the most porous rocks; so water will percolate through it fairly easily. Shale and clay are almost impervious to percolating water. It is called the "delayed run-off" because it does eventually reach the surface again and run off.

34. **Water Table, Springs and Artesian Wells.** —This downward percolating water moves until it reaches impervious strata, such as clay, and collects above it, forming a more or less horizontal layer of saturated rock or soil. The upper surface of this saturated zone is called the **water table.**

The water table is everywhere present, but at varying depths, the depth being dependent on how far the impervious layer is beneath the surface and on the amount of precipitation. The depth of the water table will vary with the seasons, being lower in dry weather. It follows the contours of the land, but will be farther beneath the surface on hilltops than in valleys. In places it reaches the surface, as in the sides of some valleys, and the water issues forth as a spring. To obtain water by digging a well, one must reach the water table. The depth of water in the well will be equal to the distance penetrated below the water table.

The water in the zone of saturation slowly seeps laterally to a lower level and eventually reaches the surface in springs, artesian wells, hot springs, geysers, etc. It may have to travel great distances and may take months and even years to do this.

Wherever the water table reaches the surface, a spring results. This most often happens on the sides of valleys; consequently springs are commonly found there. The water which has soaked into the ground reaches the surface again, but at a lower level.

Artesian springs are deep-seated, the water rising from a saturated zone some distance below the surface. The saturated rock lies between impervious strata; and the exposed porous rock, which serves as the **intake,** is above the level of the spring. (Fig. 40).

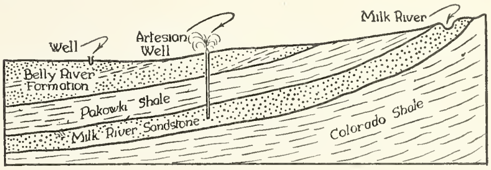

FIG. 40

Section of an artesian area in southern Alberta; the water saturated horizon, the Milk River sandstone, lies between impervious shale formations.

If no fissure exists, then a hole drilled to the saturated horizon produces a flowing well or artesian well, provided this outlet is below the elevation of the intake, providing a sufficient pressure or "head". In Southern Alberta there is an artesian area extending from Foremost to Bow Island. Here the sources of the water is the Milk River sandstone, which lies between the impervious Pakowki and Colorado shales. The intake is where this sandstone formation is exposed along the bed and valley of Milk River north of Coutts. The strata dip to the northeast. Water from the river soaks into the porous sandstone and seeps downward; therefore holes drilled through the Pakowki shale to these strata north and east of Milk River and at a lower elevation may become artesian wells. (Fig. 40).

Hot springs are mostly found in mountainous regions. The underground water has been heated by contact with hot rocks. The rocks were heated by friction when the mountains were raised and have been slow in losing heat, for rock is a poor conductor of heat. Geysers are associated with volcanic regions. They are dealt with in a later chapter (p. 70). Underground water is important not only as a source of water for streams, wells, etc,. but also as an agency in forming ore deposits by concentrating the minerals (see page 43). In such cases the ore body lies in the saturated zone just below the water table.

35. **Caves and Sink Holes.**—In places where limestone is the bed rock, **caves** and **sink holes** may be formed by the underground water. This

water will seep downwards along bedding planes and down joints and cracks, dissolving the rock, and in time producing large openings (Fig. 41). The Caves of Cheops (or Caves of Nakimu) near Glacier, B.C., in the Selkirk Mountains, were formed by the solution of limestone of the Nakimu formation of Precambrian age by underground water. The Mammoth Cave of Kentucky and the Carlsbad Cave of New Mexico are perhaps better known caves of similar origin.

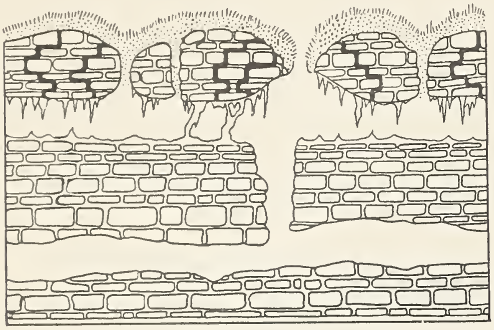

FIG. 41

Caves in limestone; the seeping of water along bedding planes and joints has dissolved the bed rock; dripping of water and its evaporation has produced stalactites and stalagmites.

Sink holes are more or less circular depressions opening at the surface. Formed by solution of the limestone bed rock, they are common in limestone countries.

36. **Evaporation.**—Surface water evaporates from the land after a rainfall, and so returns to the air. Other water is carried to the surface by capillary action and there evaporates. Plants also absorb enormous quantities of water from the soil and return it to the air through the stomata of the leaves by transpiration.

37. **Immediate Run-off.** — This varies from one-third to one-quarter of the total rainfall. A number of factors determine this amount, the most important being:

(1) The rate and amount of the rainfall.—In a heavy downpour more water will run off than in a steady rain, as water will not have time to soak into the ground. Then too, after the upper layers of the earth are saturated, more water will tend to run off.

(2) The porosity of the ground.—The lighter (i.e. the more porous) the soil is, the faster the water will be able to soak into it, and the less water will run off. Therefore the immediate run-off will be less from sandy soils than from clay soils. Frozen ground tends to increase the run-off, as it is less pervious to water.

(3) The dryness of the ground.—If the ground is dry, more water will soak into it, thus lessening the run-off.

(4) Steepness of the slope.—On a steep slope more of the water will run off before it has time to soak in than on a gentler slope. Steep slopes, then, increase the run-off.

(5) Luxuriance of vegetation.—Where there is much vegetation, the soil is generally spongy and very absorbent on account of the high humus content. Therefore the rain soaks in. Besides, the tangle of roots and branches tends to hold the water. The leaves hold drops of water on them, thus lessening the run-off.

38. **Perennial Flow.**—The steady flowing of streams is made possible by the underground water (or delayed run-off) which, issuing forth as springs, etc., gives a constant supply of water. The immediate run-off will cause a temporary rise in the level of a river. A spell of hot, dry weather in the mountains will have the same effect by rapidly melting ice and snow. Sometimes the rivers of Alberta are high in summer from the melting of glaciers in such weather. Lakes and swamps tend to regulate the flow of rivers by keeping their volumes constant, for rivers flowing out of lakes and swamps are not subject to the fluctuation in volume that other rivers are.

In arid regions where there is little vegetation the streams may be intermittent, i.e., their flow is so irregular that at times their beds may be dry, while at other times, as in spring when the snow melts or after a heavy rainfall, the streams may be torrents.

39. **Floods.**—As noted above, the immediate run-off depends on a number of factors, and various combinations of these factors might cause floods. Thus heavy rains in the early spring when the ground is still frozen may cause floods. The valley of the Ohio has been flooded many times for this reason. Exceptionally hot weather in the early spring may cause flooding if the stream beds are not big enough to accommodate the extra volume of water from the rapid melting of snow. Deforestation increases the danger of flooding, for forests reduce the immediate run-off (see above).

Floods are very destructive of life and property, especially the latter. The Mississippi is a well-known offender in this respect, and millions of dollars have been spent in an effort to alleviate the danger.

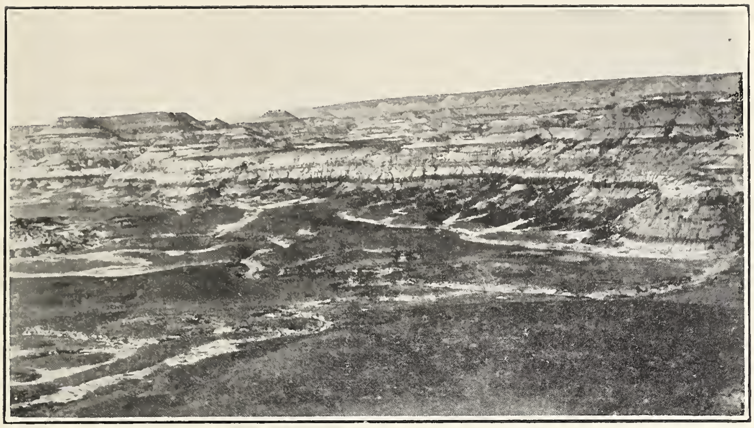

FIG. 42

Badlands of the Red Deer River near Drumheller; a coal seam is seen in the foreground, and a mesa on the extreme left; strata belong to the Edmonton formation.

40. **Basin, Valley and Divides.**—The topography of a region shows it to be made up of elevations and depressions. Precipitation which does not soak into the ground runs off the hills and other prominences and collects in the low areas to form lakes or streams. The area which collects the precipitation and contributes it to a river or lake is called a **basin,** and the depression in which the water collects is a **valley.** The high land between basins and from which the water runs off in different directions is a **divide** or **watershed.** A basin might be compared to the sides of a dish, the bottom of the dish to the valley, and the rim to the divide.

Basins and valleys will then vary in size, and also they will lie one within another. For example, the Rocky Mountains in Alberta form a divide between two major areas; rain falling on the western slopes finds its way to the Pacific Ocean, whereas rainfall of the eastern slopes eventually reaches the Arctic Ocean, Hudson Bay or Gulf of Mexico. The areas on each side are composed of basins and valleys. On the eastern side some of these are the ones which collect rainfall for the Milk, South Saskatchewan, North Saskatchewan, Peace, and Athabaska Rivers. Then these basins and valleys can in turn be shown to be made up of smaller basins and valleys which are the drainage areas of their tributaries. Thus, the basins and valleys of the Old Man, Bow, and Red Deer Rivers are parts of the basin and valley which collect water for the South Saskatchewan River. Likewise, the basins and valleys of Brazeau and Clearwater Rivers are subordinate to the basin and valley of the North Saskatchewan River.

Basins change in shape and area, for as erosion proceeds, they get larger if they are able to encroach on other basins by moving back the divide, but on the other hand they may be encroached on, and the drainage areas reduced.

Valleys have been carved into the land by the water which the basins have contributed. Evidence of this is seen by the following features: (1) Form. This varies according to the steepness of the slope and the hardness of the rock. If there is a steep slope, the valley will be deep and narrow (i.e., a gorge) ; and, of course, if the rock is comparatively soft and easily eroded, deeper valleys will result; (2) Size. A large stream has a large valley, and a small stream has a small valley; (3) Material in transportation. All streams carry material with them. This material could have come only from the sides and bottoms of the stream beds; therefore streams are eroding their own beds.

41. **Rain Sculpture.** — Where there is little vegetation to hold the water, the immediate run-off is considerable, and therefore the land will be gullied and rendered unfit for use by man; also mesas, buttes, small hills and knolls (remnants of erosion) are left in the valley. In arid lands the effect of rain erosion is particularly severe. Such areas thus affected are called **bad lands** for they are difficult to traverse. The bad lands of Red Deer River which are famous for their dinosaur remains, are an effect of rain erosion (Figs. 1, 42, 43). Here the bed rock, the Edmonton formation, is a soft, bentonitic, easily-eroded sandstone.

Deforestation of land has produced bad lands in many parts of the world. Italy and China have bad lands in some parts owing to thoughtless destruction of the forests. They are beginning to form along Vaal and Orange Rivers in South Africa, for cultivation has removed protecting vegetation, and erosion is proceeding so rapidly that a serious problem is created for which the government must find some solution. Afforestation (the planting of trees) is being tried with apparently satisfactory results.

Earth Pillars (or **Earth Columns**) are another result of rain erosion. They are formed by the action of rain on a loose mixture of soil and boulders, generally boulder clay formed from the ground moraines of valley glaciers. A large stone or hard layer protects the material underneath, while the surrounding material is washed away. In most cases the capping boulder or layer can be seen in place. The **hoodoos** seen near Banff and Jasper are earth pillars, formed by rain erosion. (Fig. 44).

Sometimes in limestone regions where the strata are inclined, the rain dissolves away parts of the layers, leaving a more or less parallel series of small sharp ridges.

42. **Erosive Power of Rivers.** — The erosive power of a river varies directly as the square of its velocity; i.e., if the velocity of a river is doubled, its erosive power will be four times greater than before. Thus erosion goes on more rapidly where the velocity is greater.

The velocity of a stream is determined by slope, volume, and the nature of the channel. The slope of a stream decreases from headwaters to mouth; and, as velocity is proportional to slope, then erosion by a river is most rapid near the headwaters, and decreases with the slope or gradient of the river. The gradient of the Colorado River, a fast flowing stream, is 7.7 feet per mile; as a result, a deep canyon has formed. A moderate stream flows at the rate of about one and one-half miles per hour; some torrents attain a velocity of eighteen to twenty miles per hour.

The volume of water in most rivers is periodical, being greatest in the spring owing to spring rains and the melting of snow. The velocity is greatest then and erosion most active.

As there is friction between the moving water and the bed of the stream, the nature of the channel will influence velocity. A smooth bed will allow the water to move along faster than an irregular bed; a stream in a narrow channel will have a greater velocity than one in a broad channel. In this connection it should be noted that the water in the middle of the stream is moving faster than the water at the bottom and sides, for in these places it is retarded by friction.

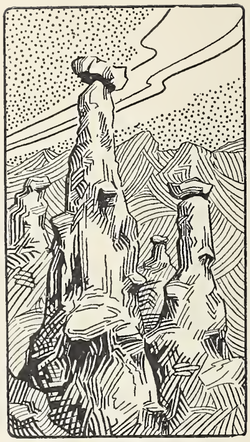

FIG. 44

Earth columns or hoodoos; note the capping rock of a boulder which protects the underlying soil.

43. **The Erosive Work of Rivers.**—The erosive work of rivers comprises: (1) denudation, or the removal of loose material; (2) corrasion, or the actual wearing away of the rock over which the water flows; (3) abrasion, or the wearing away of the material which the river carries by grinding it together; (4) quarrying, or the undermining of the banks or of the stream bed at waterfalls; (5) corrosion, or the solution of the rock.

(1) **Denudation** occurs chiefly at the headwaters of a river where the rain water runs off slopes, carrying the loose material weathered from the rocks with it to the streams. These in turn transport it to the river. To a lesser extent it occurs in river valleys, where material is loosened by weathering and falls into the river.

(2) **Corrasion** is the most important of the erosive activities of rivers and streams. By this means the bed is deepened and widened, for the load acts like a file and grinds away the bed. It is accomplished by the mechanical load which the stream carries, viz., the sand and

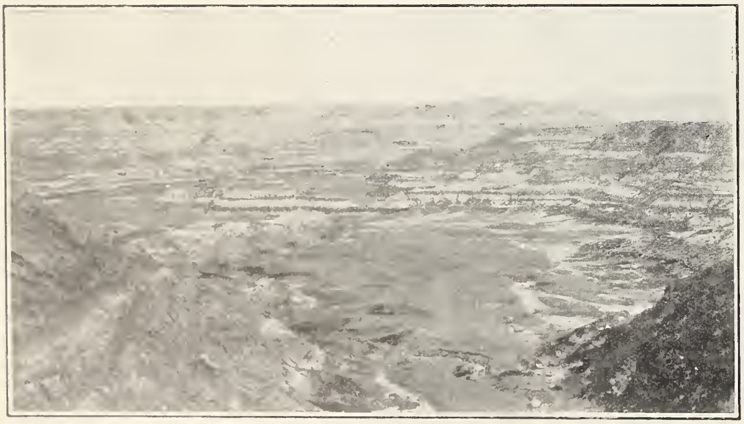

FIG. 43

Badlands of Red Deer River near Drumheller.

pebbles obtained by denudation or corrasion farther upstream. This load is easily carried, for the buoyancy of water reduces its weight from one-third to one-half.

The power of a river to carry a load of materials varies as the sixth power of its velocity (Law of Transporting Power of Rivers). Thus if the velocity is doubled (as is easily possible in spring), the stream is capable of carrying a load 2 to the sixth power or sixty-four times as great as before; thus if it can roll along a stone one inch in diameter at a certain speed, it can roll along a stone 4 inches in diameter when the velocity is doubled. Near the headwaters, then, where the velocity is greater, the load might consist of clay and sand in suspension, and pebbles and boulders rolled along the bottom; but farther downstream where the velocity is less, the load might be only clay in suspension, and sand carried along the bottom. The size of the fragment carried depends not only on velocity, but also on the shape and specific gravity of the fragment; round fragments, which present a greater surface to the current than flat ones, are more easily carried along; and fragments of light rock are more easily carried than those of heavy rock.

Water flowing out of lakes is generally clear, having lost its load in the lake. It has, therefore, little power of erosion by corrasion. The Niagara River is a good example of this.

Corrasion is most active in spring, when increased volume results in a greater velocity. Then it is noticed that the water is muddy; therefore the load is heaviest. A heavy rain will produce the same effect. In the fall the waters are generally clear, and then the load is lightest.

(3) **Abrasion.**—As the load is carried downstream, the rock fragments bump together and grind against each other, and are worn away in the process. This explains to a great extent the rounding of sand grains, pebbles, and boulders. The size of the fragments in the channel should decrease from headwaters to mouth as a result of abrasion. Such is actually the case.

(4) **Quarrying,** by undermining the banks, not only widens the river valley but supplies new material, pebbles and sand, for corrasion. Quarrying is carried on where the river takes a bend, throwing the water up against one bank. The water cuts away the bank underneath, and the result is a cave-in, which produces a steep bank (or **cut bank**). (Figs. 6, 33). One does not have to follow a stream very far to find these steep banks.

Waterfalls are undermined by the spray and the churning of the falling water. Large masses of rock are loosened in this way, and the waterfalls retreat upstream (Fig. 45).

(5) **Corrosion** or erosion by solution is not very important unless limestone or other easily soluble rock is encountered by the stream. Most of the load in solution is contributed by underground waters.

44. **Amounts of Sediments Carried by Rivers.** Vast amounts of materials are transported to the sea by rivers each year. It has been estimated that the Mississippi River carries down to the Gulf of Mexico each year 406,250,000 tons of sediment in suspension (gravel, sand, clay) and 120,520,000 tons in solution (calcium carbonate or lime, calcium sulphate, sodium chloride, silica, other carbonates and sulphates, and iron oxide). If taken evenly from its drainage basin it would lower the basin one foot in 6,000 years. The Hwang Ho River of China carries down each year enough sediment to lower its basin one foot in 1,500 years. The St. Lawrence River does not carry as much, for it drains lakes which act as settling basins for the sediment, and the water leaving the Great Lakes is comparatively clear.

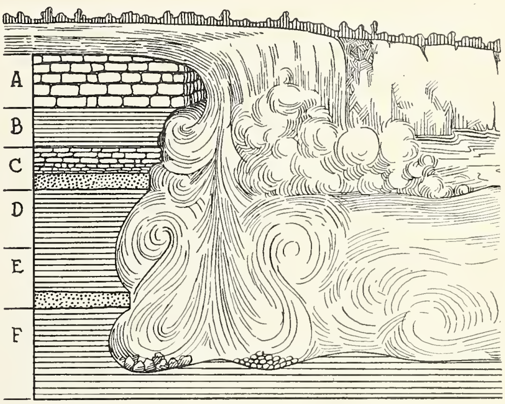

FIG. 45

Section of Niagara Falls; undercutting by the water causes large masses of rock to drop and the falls to retreat upstream; A Niagara limestone or Lockport dolomite, B Rochester shale, C Clinton formation, D Medina formation, E Cataract shale and sandstone, F Queenston shale.

Streams which are deepening and widening their valleys are said to be **degrading,** while streams which are depositing material in their beds are termed **aggrading.** A river could easily be degrading near the headwaters and aggrading near its mouth. The Mississippi, Fraser, and Mackenzie Rivers are aggrading in their lower stretches.

45. **Potholes.**—These are a feature of swift-flowing streams. They originate as small de-

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pressions in a rocky stream bed, and are deepened and widened by swirling water, which swishes sand and stones around in them, grinding away the bed rock. Potholes are circular in shape, getting somewhat larger below. They may be as much as 20 feet in diameter and about as deep. Their size, though, is limited, for the water loses its force with depth. When a number of them join together, they are very effective in deepening the valley. They commonly form at the bottom of cascades.

46. **Waterfalls and Rapids.** — Rapids grade into waterfalls according to the slope. In some waterfalls the slope of the stream bed is vertical, but no hard and fast rule is used to distinguish waterfalls from rapids.

Rapids are rough water which is formed in the stream bed where the water passes from resistant to weaker rocks. The weak rock is worn away more quickly, causing a sharp increase in the gradient of the river. Alternate strata of hard and soft rock which dip downstream produce rapids. (Fig. 46).

When the water flows from a thick resistant stratum to a soft rock, waterfalls may result. Niagara Falls are formed by the water passing over the Lockport Dolomite (80 feet thick) to softer shales with some sandstone and limestone layers (Fig. 45). The more rapid erosion of the shale has produced a falls 160 feet high, for the limestone is undermined and a steep cliff produced. In the illustration notice how the Lockport Dolomite is undercut by water currents and spray. From time to time large masses of it fall, changing the contours of the escarpment. Alexandra Falls on Hay River, N.W.T., are 106 feet high. Where they occur, thick strata of Devonian limestone overlie shales of the same period. These falls are formed in a manner similar to Niagara Falls.

Undercutting (or quarrying) of the stream bed by the water causes the waterfall to move upstream. Niagara Falls on the Canadian side are moving upstream at the rate of five feet a year, and Alexandra Falls at about the same rate.

A small waterfall is sometimes called a **cascade** and a large waterfall, a **cataract.**

Waterfalls and rapids are also formed in other ways. When the stream passes from hard resistant rocks to soft, easily-eroded rocks, waterfalls or rapids result. Another type, **fault plane waterfalls,** may be caused by faulting. In these the water tumbles down the eroded fault plane. The cascade which tumbles down Cascade Mountain at Banff forms a waterfall of this type. **Joint plane waterfalls** are a special type, formed by the breaking away of huge slabs of rock along joint planes. Another type of waterfall is caused by glacial action. In this the natural watercourse to the bottom of the valley has been worn away by glacial action (if such a bed existed previously) so that on the retreat of the glacier, the water falls over or down a steep bank to the valley bottom. (Fig. 83b).

* * *

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47. **Young, Mature and Old Valleys.**—Owing to forces of erosion and weathering, valleys change as they grow older. In changing they develop certain characteristics by which they

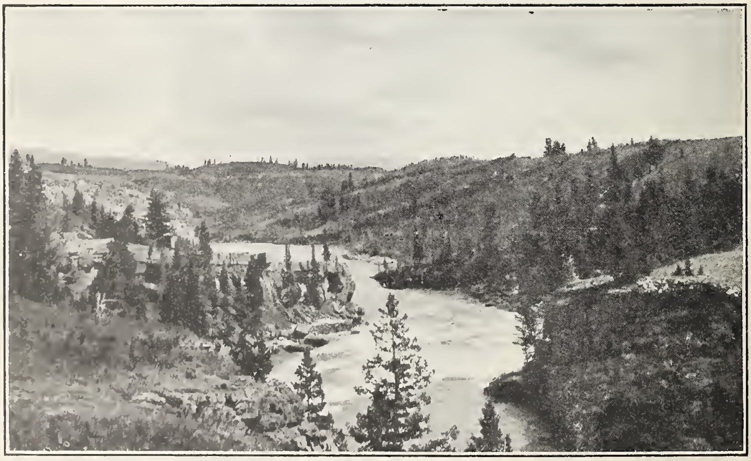

FIG 46

Rapids on Bow River near Calgary Power Company's lower dam; rapids are caused by the inclined and resistant beds of sandstone and conglomerate which belong to the Cardium formation (a formation lying between the Upper and Lower Benton formations).

are classified as young, mature, or old valleys. (Fig. 47). These terms do not apply to their age in years but to their appearance. To study these characteristics, one had best follow the development of a valley from youth to old age. Let us start with a sea bottom recently lifted above sea level by an earth movement.

Rainfall would run off the slopes and collect in depressions to form a stream which would cut a channel for itself as long as the rain would continue to fall. This stream, in time, would be joined by other smaller streams, and the more tributaries it would get, the longer the water would run in the channel, and therefore the deeper and wider would become the channel. In this process the channel cuts farther back from the mouth, collects more tributaries, and may even tap lakes and marshes which would make the stream run continuously. The tributaries supply the bulk of the tools of erosion (sand, pebbles, and boulders), and the stream uses these to cut its channel deeper and deeper into bed rock, striving, as it were, to reduce it to sea level or what is known as **base level.** The valley is still **young** and may possess the following characteristics:

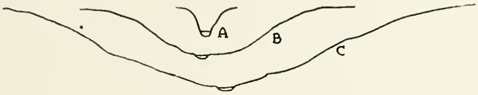

FIG. 47

Profiles of valleys in different stages of development; A young valley, B mature valley, C old valley.

(1) In cross-section the valley is V-shaped.
(2) The valley is narrow and comparatively straight, and its banks are steep.
(3) Its stream has a high velocity, and therefore is eroding fast.
(4) The stream has few tributaries.
(5) Its divides have indefinite boundaries, for rapid erosion is enlarging them.
(6) It may have lakes, rapids and waterfalls.

Many thousands of years have been required for the stream to develop this far.

A young valley is sometimes called a **gorge** if it is especially narrow and has steeply-rising high walls which have been rapidly cut by the swiftly flowing stream. A gorge is also called a **gulch** or **ravine.** A **canyon** is a large gorge, though sometimes the two words mean the same; the Grand Canyon of Colorado is well known. A **dell** is a small secluded valley or ravine; and a **glen** is a narrow valley between mountains or hills.

A **gully** is a small ravine which has been formed by an intermittent stream. It is formed in an arid climate where there is little vegetation and the water runs off rapidly and erodes steep-sided trenches. Gullies are prominent features of bad land topography; they are therefore common along Red Deer and South Saskatchewan Rivers (Figs. 42, 43).

As the stream cuts its bed deeper, its slope or gradient becomes less; therefore its velocity is reduced, and hence its erosive power. The valley is now becoming **mature.** Curves or **meanders** develop as the stream begins to wear away the sides of its bed rather than the bottom. Meanders are produced by the water hitting an obstruction, such as relatively more resistant rock, and being deflected to the opposite bank. From there it is deflected to the other bank, and so back and forth downstream. The impact of the current and its load against the bank undercuts it, and in this manner steep or vertical banks (cut banks) are produced on alternate sides of the valley (Fig. 49); at the same time the curves migrate downstream. As time goes on, these curves become sharper and the channel winds back and forth between the

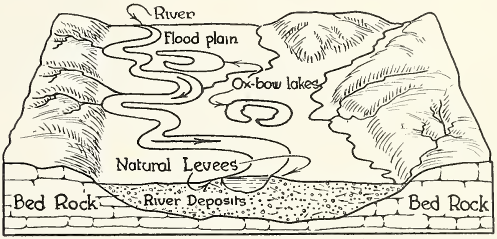

FIG. 48

An old valley with natural levees and ox-bow lakes.

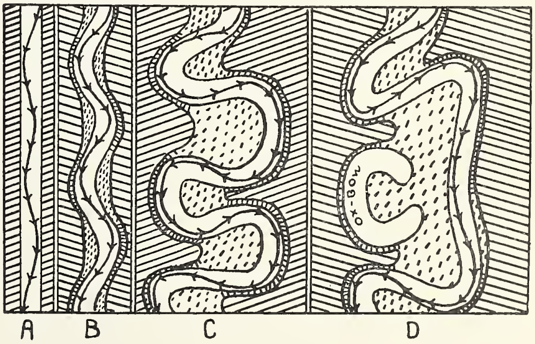

FIG. 49

Diagram to illustrate the development of meanders in a river; in A the channel is straight, but the current (indicated by arrows) is winding because of an obstruction above; in B the channel has also developed curves but not to the same extent as the current, and cut banks and slip-off slopes are produced; in C the river is meandering in a widened valley, and two meanders almost meet; in D the meanders have met, and the part cut off is an ox-bow lake. (River channels are in white, slip-off slopes are stippled, and cut banks are shown by short radiating lines.)

banks of a wide valley. (It is to be noted that these meanders widen the valley but do not deepen it much). As a steep bank is produced on the outside of the curve, material is deposited on the opposite or concave side of the channel, producing a river flat or slip-off slope. The valley is further widened by the weathering of its banks. In the figure (Fig. 49) the arrows indicate the main current of the river. Notice how it swings from bank to bank.

The river is mature at its mouth first, and, as time passes, this maturity extends back from there. The chief characteristics of a mature (or middle-aged) valley are:

(1) The stream meanders in a wide valley.

(2) It has cut banks and river flats.

(3) Its sides are moderately dipping.

(4) It has well-defined divides.

(5) It has many tributaries.

(6) Hills are left here and there. These hills are known as remnants of erosion; (Cypress Hills, Hand Hills and Swan Hills south of Lesser Slave Lake are erosion remnants). The North Saskatchewan and South Saskatchewan Rivers have mature valleys.

As the valley approaches old age, the surrounding country becomes reduced to a **peneplain,** i.e., a plain having a low, rolling surface. The banks of the valley are low. The gradient of the stream bed is so small that the water barely moves along; therefore the stream is aggrading its channel. In places the stream may have aggraded its bed so much that it has been raised above the level of the surrounding country. Such river banks are called **natural levees** (Figs. 48, 50), and are characteristic of the Mississippi and Nile Rivers. Exceedingly high water sometimes breaks through these natural levees, and disastrous floods result. In some places along the Mississippi, artificial levees have been built up to prevent flooding. Sand bars are common in the river of an old valley. As the level of the country is lower than the river banks, drainage will be poor and swamps will develop; moreover, the river will have few tributaries. Meandering has gone on so far that the channel is very winding; in places the water has cut across the narrow necks of land. The part cut off becomes sealed with sediment at the ends and is known as an **ox-bow** lake (Figs. 48, 49). As a result of these cut-offs, the channel is made comparatively straight. When the river is high, sediment is deposited, building up **flood plains** or **alluvial plains,** which are valuable for agriculture.

48. **Intrenched Meanders and Estuaries.** — Sometimes a river valley has been rejuvenated (made young again) in parts of its channel in maturity or old age. This rejuvenation is effected by the river's acquiring a steeper gradient from an uplift, and so cutting a narrow gorge in the bottom of its valley. The existing meanders of the old river bed are carved deeply into bed rock, making **intrenched** or **incised meanders** (Figs. 50, 51). Colorado River has been rejuvenated, hence the great depth of the canyon (Grand Canyon)—over 6,000 feet at one place. On the other hand, a sinking of the land may cause the sea to occupy the whole of the river valley at its mouth, "drowning" the river. The **estuary** is that part of the river which has been invaded by the sea. Estuaries make excellent harbors, as evidenced by London on the Thames, Montreal on the St. Lawrence, and New York on the Hudson.

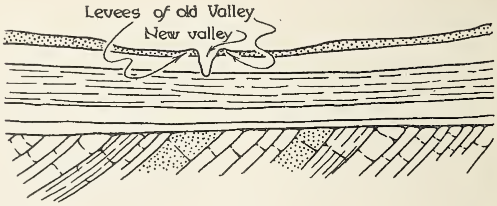

FIG. 50

A rejuvenated river; uplift of the region has given the stream an increased gradient and greater erosive power so that it cuts downward; in section the valley resembles a young valley but may have natural levees.

If the land sinks far enough the whole peneplain again becomes sea bottom; then deposition of sediment begins and continues until another uplift occurs. The newly-formed exposed rocks are attacked by the agents of weathering and erosion and the cycle of denudation begins anew.

49. **River Flood Plains.—Flood plains** or **river flats** are a common feature of mature and old valleys, for these are wide enough to permit the stream to meander in them (Figs. 48, 49). Flood plains are built by the stream's over-flow-

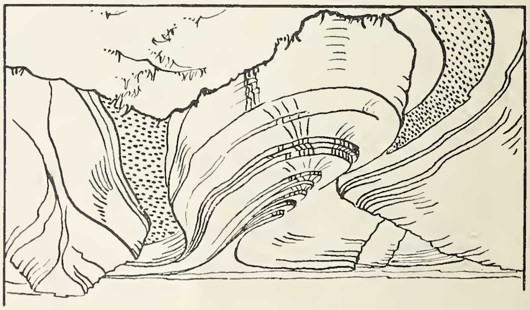

FIG. 51

Intrenched or incised meanders in San Juan Canyon, Utah; this region was uplifted when the river was quite meandering (about stage C in Fig. 49), and these meanders were cut deeply into bed rock. (Water is shown by stippling.)

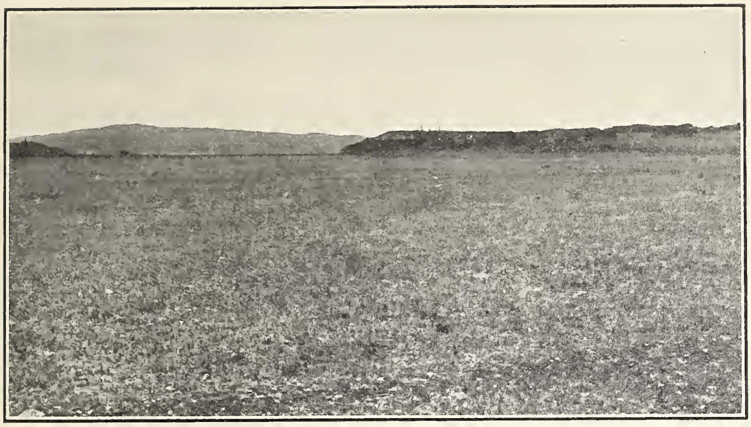

FIG. 52

An old terrace can be seen on the right and a terminal moraine in the background; along Bow River near Morley.

ing its channel, and because of a decrease in velocity (hence carrying power) dropping part of its load. Most of this load is deposited near the channel, building up a natural levee; as a consequence the flood plain slopes gently from the stream to the sides of the valley (Figs. 48, 49, 50). River flats are common in the larger streams of Alberta. With each flood, the flood plain is built higher above water level by the deposition of sediment. It is estimated that the Nile River is building up its flood plain in this way at the rate of 4½ inches per century.

Flood plains are generally well suited for agriculture, supporting large populations, as, for example, those of the Nile, Hwang Ho, Mississippi. The flood plain of the Nile is about 500 miles long, and from five to 15 miles in width.

50. **River Terraces.**—River terraces are formed by a degrading, meandering river. As the river cuts its channel deeper, the slip-off slopes are left above the water level, forming a flood plain,which, as it becomes too high to be flooded, is known as a **river terrace** (Fig. 52). Lateral erosion by the meandering river gives these terraces a crescentic shape.

River terraces are also formed by the uplift of the region, which causes the slip-off slopes and flood plains to be left high above the rapidly eroding river. Glaciers and glacial deposits might temporarily dam a river forming a lake in which sediment is deposited. On the removal of the dam, the river cuts its channel through these deposits, leaving terraces; though these are more properly called **lake terraces.** Such terraces are common in Alberta, having been formed during the Ice Age.

51. **Deltas.** — When the water of a river is emptied into a lake or sea, it loses its transporting power, for its velocity is then suddenly checked. Its mechanical load—gravel, sand, and clay —is deposited at the mouth, forming a **delta.** It is built up gradually from the bottom, and may rise above the surface of the sea or lake in low water.

Deltas are roughly triangular in shape, the apex of the triangle pointing towards the mouth of the stream. The gravel, sand, and clay are deposited near the mouth, with the finest clay farthest from it. The beds of a delta are spoken of as topset, foreset, and bottomset (Fig. 53). The topset beds are coarser, whereas the finer material makes up the bottomset beds. As the delta tends to block the mouth of the river, the river is split up into a number of streams or distributaries. These wind across the delta and deposit their loads at its farthest edge, thereby extending the boundaries of the delta.

Deltas are being built up at the mouth of most rivers. The Mississippi, McKenzie, Fraser, Nile, Danube, Ganges, Hwang-Ho, and many other rivers have large deltas, some being hundreds of square miles in extent. The delta of the Nile is about 100 miles wide. On account of their fertility, deltas are intensely cultivated wherever the climate is suitable. The delta of the Hwang-Ho River is one of the most densely populated regions in the world (800 per square mile).

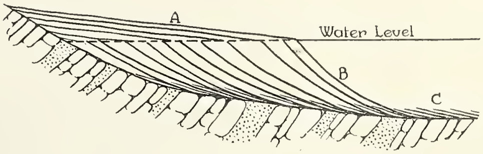

FIG. 53

Section of a delta; A topset beds (coarsest), B foreset beds and C bottomset beds (finest sediments).

Deltas are built up rapidly in shallow water, or where the shore is being uplifted. On the other hand, a sinking shore or a shore that is washed by strong currents will retard the development of deltas, for a sinking shore lowers the bottom as fast as it is built up, and, in the latter case, the sediment is swept away by the current.

Deltas tend to make a shore line irregular, for they project out into it, but the action of waves and currents tends to keep it straight.

Sea Island and Lulu Island are part of the Fraser River delta. This delta is being extended out into the Strait of Georgia at the rate of 10 feet a year. Anticosti Island is not the delta of the St. Lawrence River; this river has none, for it drains lakes and hence carries little sediment.

52. **Alluvial Fans** or **dry deltas** are deposits of sediment which have been dropped by tributary streams which have had their gradients suddenly lessened as on reaching the bottom of a valley. They are common in mountainous regions (Fig. 54). Unlike deltas, they are formed on land (hence dry deltas) and are generally of coarser material (boulders, coarse gravel, and sand, etc). The material also in them is angular, for it has not been carried far, and has suffered little abrasion. An alluvial fan with a steep slope is called a **cone delta.** Alluvial fans vary in size from a few square feet to many square miles. Small ones can be seen in a gutter or ditch after a heavy rain.

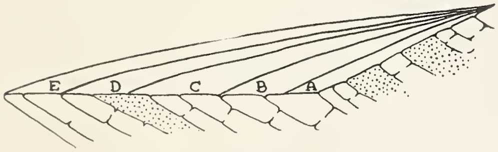

FIG. 54

Diagram of a section of an alluvial cone or dry delta showing how it is built up; A was the first bed to be deposited and E is the latest.

53. **Formation of Lakes.**—Lakes are formed by some interference with drainage. This would occur, for example, when water resulting from precipitation is interrupted on its way to the sea and collects in basins. Lake basins originate in a number of ways, some of which are as follows: glacial action, volcanoes, landslides, river cut-offs (ox-bow lakes), alluvial cones, warping of the earth's crust, and faulting.

(1) **Glacial action.**—Glaciers transport material and leave it at its lowermost margin, where it collects to form a moraine. Thus a mountain glacier may block a valley, and on the retreat of the glacier up the valley, water collects in the basin so formed. Such is the origin of Moraine Lake near Lake Louise (Fig. 55). Continental glaciers moving across the country will dam rivers, and cause extensive formation of lakes. This happened in Canada during the Ice Age; and by this action the courses of many rivers were changed permanently in places. Lakes might still occupy the old river valleys. The lakes can be recognized in some cases by their shape, being long in comparison to their width.

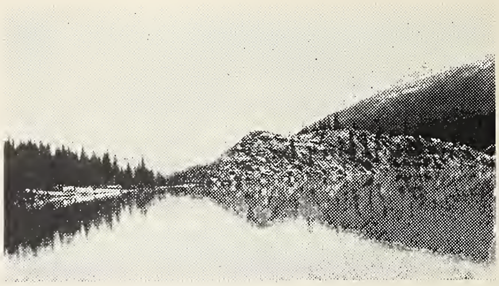

FIG. 55

Moraine Lake near Lake Louise; the heap of rock debris blocking the valley is a terminal moraine.

Moreover, as the continental glacier advanced, the weight of the ice depressed the land, so that in front of the glacier there would be depressions in which water from the melting ice collected. As the glacier retreated, a lake would form behind it for the same reason.

Kettle lakes occupy depressions caused by the melting of huge blocks of ice which were mixed up with the morainal material. They are small lakes in comparison to other lakes.

The grinding of glaciers in a valley sometimes scoops out a basin in the rock, which, on the retreat of the glacier, collects water to form a lake. Such a lake is a **tarn,** and often occupies a cirque on the retreat of the glacier.

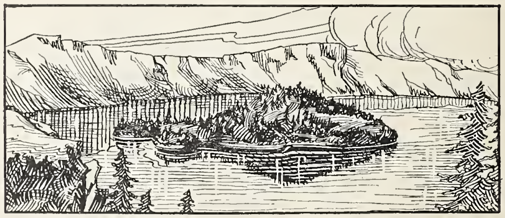

FIG. 56

Crater Lake, Oregon, occupying a caldera; the island in the lake is a cinder cone.

(2) **Volcanic action.**—A flow of lava might block a valley transforming it into a lake. Volcanoes might also form a lake basin by the collapse of its crater, creating a **caldera** which

may be several miles in diameter. Crater Lake in Oregon occupies the caldera of an extinct volcano, Mt. Mazama (Figs. 56, 57).

(3) **Landslides.**—These may be of sufficient size to block a stream, allowing the stream to collect behind it and to form a lake. Such lakes will be found in hilly or mountainous districts.

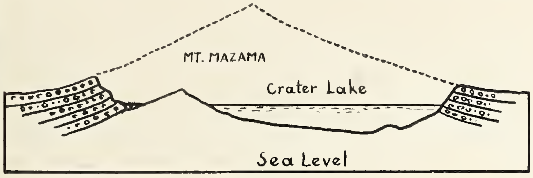

FIG. 57

Restoration of Mount Mazama, an ancient volcano in Oregon; much of the cone has dropped in to form a large basin (caldera) in which water has collected.

(4) **Alluvial cones.** — A tributary stream sometimes builds up a cone large enough to block the main stream and transform it into a lake.

(5) **River cut-offs.**—The formation of ox-bow lakes, a feature of old river valleys, has been discussed in connection with river valleys in old age (Figs. 48, 49).

(6) **Warping of the earth's crust.** — Sometimes the earth's crust has been warped or bent to form a trough, which might be occupied by a lake. Great Salt Lake is an example of this type.

(7) **Faulting.**—In some cases the warping of the earth's crust, mentioned above, has gone so far that the strata have been fractured (or faulted). Some valleys have been formed by the faulting of huge blocks of the earth's crust, which have then sunk lower than the surrounding rocks. These are **rift valleys**, and water might collect in them. The rift valley of Africa, now occupied by a series of lakes, of which Lake Tanganyika is the largest (Fig. 58), originated in this way. The basin of Dead Sea is a rift valley. Many of the lake basins in the northeastern corner of Alberta were formed by fracturing of the strata (Fig. 59). The lakes occur in chains which run in the same direction as the faults.

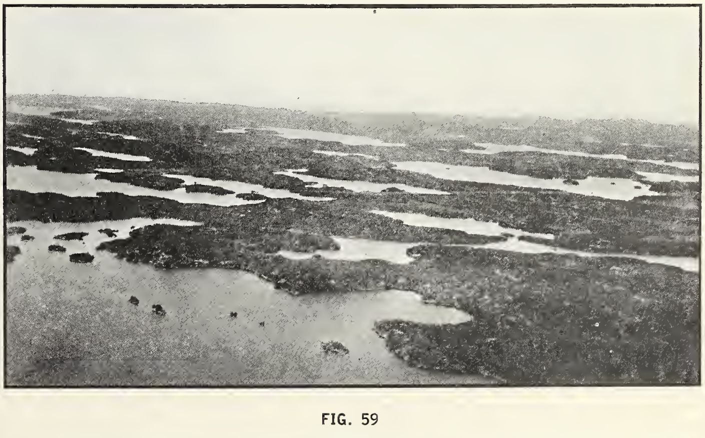

FIG. 59

Aerial photograph of a portion of Charles Lake area; note the trend of the chains of lakes, which is north - south; the lakes occupy basins which have resulted from faulting of the rock along more or less parallel lines.

(8) **A new land surface,** i.e., a sea bottom recently uplifted, will have depressions in it which will act as lake basins. These depressions may have been formed by the unequal deposition of sediment on the bottom.

54. **Salt Lakes.**—Some lakes have no outlets, and the only way for removal of the water is by evaporation. Thus, as evaporation proceeds, the waters become saltier and saltier. Salt lakes are characteristic of dry climates where evaporation is rapid. As noted in a previous lesson, the source of the salt is decomposed rock, from which the water has dissolved certain minerals. In some salt lakes the water is so salty that it can hold no more in solution and so deposits the salt on the bottom. Carbonate of lime, gypsum (calcium sulphate), common salt (sodium chloride), and sodium sulphate are salts commonly deposited. With increasing saltness, aquatic life in lakes is killed; consequently, in some salt lakes there is no life.

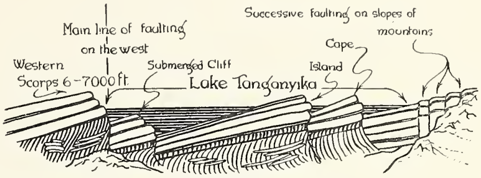
Main line of faulting on the west
Successive faulting on slopes of mountains
Cape
Western Scarps 6-7000 ft
Submerged Cliff
Island
Lake Tanganyika

FIG. 58

Section across Lake Tanganyika, Africa, showing the fault block type of lake basin; tilting and dropping of the faulted blocks of strata have produced a narrow basin many miles in length.

The largest of salt water lakes is the Caspian Sea (Fig. 60). This lake is 85 feet below sea level—the evaporation from it being so great. Nevertheless its saltness is less than that of the sea, for it is younger; moreover, the Volga and other rivers pour into it great volumes of fresh water. Kara Bugas Gulf, a bay of the Caspian, is much saltier than the sea. Here the basin is quite shallow, and no fresh water comes into it.

The Dead Sea is one of the saltiest of all lakes, its water being about 25% salt (by weight). It is about 1,200 feet below sea level.

Great Salt Lake in Utah is a remnant of a much larger lake, Lake Bonneville. Lake Bonneville was the size of Lake Huron, and where Salt Lake City now stands, the water was once 1,000 feet deep. As the water evaporated the lake became saltier, until now the Great Salt Lake is about 20% salt.

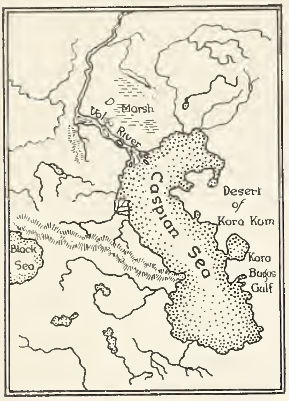

FIG. 60

Caspian Sea, an inland sea with no outlet, and Kara Bugas Gulf; the waters of Caspian Sea are kept comparatively fresh by the rivers flowing into it, but salts are being precipitated in the shallow Gulf where evaporation is quite rapid.

Some salt lakes serve as a source of salt, this being obtained by allowing the water to run into shallow pans, from which the water evaporates leaving the salt. Sometimes the water in the lake has completely evaporated leaving beds of salt which can be mined. Frederick Lake in southwestern Saskatchewan is such a lake, from which sodium sulphate is obtained. The salt is dug up at the surface of the lake, dehydrated (water removed), and sent to Eastern Canada, where it is used in the paper and metallurgical industries.

55. **Life History of Lakes.**—Lakes are only temporary geological features, and, we have seen, may be characteristic of young and mature valleys (with the exception of ox-bow lakes). Their destruction comes about in any of four ways, viz.: (1) removal of the dam, (2) down-cutting of the outlet, (3) filling-in, (4) complete evaporation.

(1) If the lake has been formed by the damming of a valley by ice or rock debris, then the melting of the ice or the washing away of the debris would release the impounded waters. Some river terraces are evidence of a temporary damming of a stream by ice, many of them having been formed during the Pleistocene epoch (at the time of the last great glaciation).

(2) All streams tend to lower their channels to base level (sea level), and this lowering of the channel may in time lower the outlet, so that the lake is drained. This process, however, is very slow, for the water has lost its tools of erosion (sand, etc.), which have settled out in the lake. Water leaving lakes is generally clear.

(3) Filling in.—This process alone will in time destroy a lake. Sediment carried by streams to the lake will be deposited there, gradually filling in the lake. As the lake becomes shallower, plants growing along its margin move in towards the centre. When the plants die, their remains help to fill in the lake. The lake now becomes a marsh or swamp, then a bog, and finally dry land with a stream meandering across it. Many lakes are swampy around the edges, a step in the filling-in process. (Fig. 34).

Peat bogs are formed by the filling-in of lakes with principally the remains of plants. As the material making up the bog is mostly vegetable matter, it burns well when dry; consequently in many countries it is dug out, dried, and used for fuel. Peat bogs are found in damp climates. Coal has been formed by the covering over of peat bogs by sediment, the weight of which squeezes out the water and compresses the remainder into rock (coal).

(4) The water may evaporate completely from a lake leaving a bed of salt. Great Salt Lake is gradually drying up.

56. **Swamps.**—Swamps are damp places on the earth which ordinarily are not covered with water. There are a number of different types.

(1) **Tundra Swamps,** common in Northern Canada, are formed by the growing of plants—if there is sufficient soil—in water lying in depressions in the bed rock. Such swamps are generally called **muskegs.**

(2) **River swamps** are found chiefly in old river valleys where the water has over-flowed its channel and remained back of the natural levee. The over-flowing may have taken place in times of flood; or it may have been caused by a tide's backing up the estuary. In the latter case, however, the swamp is more properly called a **salt marsh.** Deltas are often swampy.

(3) **Arid land swamps** are seasonal, enduring only in the spring when water collects to form a shallow lake in which water plants grow. Generally by late summer all the water has evaporated. They are also called **salines** or **playas.**

(4) Swamps and marshes are also formed on the sea coast where the shore has a very gentle dip or where a delta is forming. These are **coastal plain swamps** or **salt marshes.** They may form also in a lagoon which has become cut off from the sea by a sand bar. In time this lagoon is filled in. First, water plants grow in it, but when it becomes dry land, they are succeeded by land plants.

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Questions:

1. (a) What is the source of all the water in lakes and rivers?
   (b) What part of the earth's surface receives most rainfall? What part receives least?
   (c) What happens to precipitation which falls to the earth?
   (d) How far does the delayed run-off sink into the earth?
   (e) Why is it called the delayed run-off?
2. (a) Make a diagram to show water table, saturated zone and springs.
   (b) Define water table.
   (c) What three factors determine the depth of the water table below the surface?
   (d) What happens to the delayed run-off after it has reached the saturated zone?
   (e) What factors would you consider in the selection of a place to dig for water?
   (f) How far down must one dig in order to get water?
3. (a) Where are springs generally found?
   (b) What features are necessary in order to have an artesian spring?
   (c) Draw a cross-section of the artesion area in southern Alberta.
   (d) Locate this area on a sketch map of Alberta.
   (e) Explain how hot springs are formed.
   (f) Give two reasons for the importance of underground water.
4. (a) Explain briefly how limestone caves are formed.
   (b) What are sink holes? How are they formed? Why are they not found on the plains of Alberta and Saskatchewan?
   (c) Where are the Caves of Cheops?
   (d) Give three ways by which water gets to the surface of the earth to be evaporated.
5. (a) What fraction of the total rainfall is the immediate run-off?
   (b) Briefly explain each of the five factors that determine the amount of the immediate run-off.
6. (a) What factors make possible the steady flow of water in streams? Give three.
   (b) How do you account for the rise of some of the rivers in summer during a hot dry spell?
   (c) What is an intermittent stream?
   (d) What are three causes of floods?
   (e) Why is the water flowing from lakes generally clear.
7. (a) Distinguish between basin, divide, and valley.
   (b) Sketch a map of Alberta to show the rivers mentioned on page 49, section 40, paragraph 2. Draw in the approximate positions of the divides that separate the basins of these rivers.
   (c) Why do basins change in shape?
   (d) Where is the Continental Divide? Why is it given this name?
   (e) Give three reasons for believing that valleys have been carved into the land by water.
8. (a) Why are the effects of rain erosion especially severe in arid regions?
   (b) What are remnants of erosion?
   (c) Why are bad lands so named?
   (d) For what are the bad lands of the Red Deer River famous?
   (e) How does deforestation aid in the formation of bad lands?
   (f) How can rain erosion be reduced?
   (g) Draw a diagram of an earth pillar. Explain how it was formed.
   (h) What are hoodoos?

9. (a) State the law of erosive power of rivers.
   (b) What three factors determine the velocity of a stream?
   (c) At what time of the year is erosion most active? Why?
   (d) In what part of a stream is the current moving fastest? Why?

10. (a) Give five ways in which the erosive power of rivers operate.
   (b) Where does denudation operate chiefly?
   (c) Explain how rivers grind away their beds.
   (d) Why are streams able to carry so much sediment in suspension?
   (e) State the law of transporting power of rivers.
   (f) A stream has its velocity increased three times. How many times is its load increased?
   (g) What three factors determine the size of a fragment that can be carried by a stream?
   (h) When is corrasion most active? Why?
   (i) When is corrasion least active? Why?

11. (a) Define abrasion.
   (b) Give two evidences of abrasion.
   (c) What is quarrying? What does it produce?
   (d) What is the work of corrosion?
   (e) Why is the water of the St. Lawrence River comparatively clear?
   (f) What is meant by an aggrading river? a degrading river?
   (g) Can a stream be aggrading and degrading at the same time? Explain.
   (h) Which of the five processes of river erosion is most important?

12. (a) How are potholes formed?
   (b) Which of the processes of erosion in rivers causes their formation?
   (c) Why is their size limited?
   (d) Where are they generally formed?

13. (a) What are rapids? How are they produced?
   (b) Draw a diagram of Niagara Falls. Explain how they were formed.
   (c) Where are Alexandra Falls? How fast are they retreating upstream?
   (d) What causes a waterfall to retreat upstream?
   (e) What is a cataract? a cascade?
   (f) What are fault plane waterfalls?

14. (a) Why may a valley old in years be termed young?
   (b) Draw a profile section of a young, mature, and old valley.
   (c) State six characteristics of a young valley.
   (d) Define: gulch, ravine, gorge, canyon, dell, gully, glen.
   (e) What are six features of a mature valley?
   (f) What is a cut bank? What is a slip-off slope?
   (g) Where does maturity in a river develop first?
   (h) Define: peneplain, natural levee, meander, ox-bow lake, flood plain, base level, remnants of erosion.
   (i) What are six characteristics of an old valley?
   (j) Draw a diagram to show how meanders develop in a river.
   (k) Give the name of a river or stream with which you are familiar. Is its valley young, mature, or old? Give four reasons for your opinion.
   (l) What is the general effect of the meandering of a river?

15. (a) What is rejuvenation of a river?
   (b) Explain how rejuvenation of a river produces incised or intrenched meanders.
   (c) How may the great depth in some places of Grand Canyon in Colorado be accounted for?
   (d) What are estuaries? Of what economic importance are they?

16. (a) What is a flood plain? Give two other names for it.
   (b) How is it built up?
   (c) Why does it slope from the channel towards the bank?
   (d) Of what economic importance are flood plains?
   (e) Give four reasons why they may be especially suited for agriculture.
   (f) Draw a diagram to show a flood plain, ox-bow, meanders, and natural levee.

17. (a) How are river terraces formed?
   (b) Explain how a delta is formed.
   (c) What conditions are most favorable for the formation of deltas?
   (d) What conditions retard their development?
   (e) Draw a diagram of a cross-section of a delta.
   (h) How are alluvial fans formed? What is another name for them? How do they differ from cone deltas?

(f) Why has not the St. Lawrence River a delta? (Two reasons).
(g) How fast is the delta of the Fraser River growing?
(h) Give three ways in which an alluvial fan differs from a river delta.

18. (a) Why does water collect to form lakes?
(b) What are six ways by which glaciers form lake basins.
(c) Explain briefly the origin of: Crater Lake, Great Salt Lake, ox-bow lakes, rift valleys.
(d) What is a large lake close to your home? Can you account for the origin of its basin?

19. (a) What two conditions are essential for the formation of salt lakes?
(b) What is the origin of the salt in such lakes?
(c) Name two seas that have their surfaces below sea level. How do you explain this fact? How much salt is there in 100 pounds of salt from each of these lakes?
(d) Where is Frederick Lake? Of what economic importance is it?

20. Explain each of the four ways by which lakes are destroyed.

21. (a) What is a swamp?
(b) Describe briefly each of the four types of swamp, viz.: muskeg, river swamp, playa, salt marsh.
(c) Which of the above types of swamp are to be found in Alberta? Where?

Suggested Activities:

1. Find out the source of the water in your closest rivers and creeks. Which of them obtain their water from melting snow and which from springs? What streams dry up in summer? Why? What causes the level of the water in streams to fluctuate? Why does the water in some Alberta rivers rise in dry, hot weather?

2. Have you ever observed that when rain falls at low elevations snow falls at higher elevations; e.g., rain may fall in a valley, but snow falls on the mountain peaks on each side? How does this lessen the danger of floods?

3. Obtain a piece of sandstone, weigh it, and soak it in water for 24 hours. Then remove it from the water, allow the water to drain off, and weigh again. Why is there an increase in weight? Is rock then a perfect solid?

4. Make a model of a water table and spring. Use damp sand clay, putting the clay at the bottom. Cut a valley down the centre. Sprinkle water on the sand and note where it comes out. Does it come out at the contact of the porous sand and the impervious clay? If so, it is a contact spring. An artesian basin may be modelled in a similar manner, and holes may be drilled to the porous layer.

5. In a heavy rain have you ever seen water running off a lawn? Why doesn't it run off? Why does water run in the street at the same time?

6. Observe that as a general rule big streams have large valleys, and vice versa. Note carefully the material of the banks and slip-off slopes. Are the banks bed rock, and the gravel of the slip-off slopes derived from it? Will river basins on the plains change shape more rapidly than basins in the mountains? Give reasons pro and con.

7. Obtain samples of water from a nearby stream at different seasons of the year, noting the level of the water on each occasion. Allow the sediment to settle in the samples obtained, and note the size of the grains. At what time of the year does the stream carry the largest grains? What relation is there between the size of the particles transported and the level of the water? Can you explain this relation?

8. Is there an aggrading stream near your home? How do you identify it as such? Is it aggrading at one season and degrading at another? What evidence forces you to this conclusion?

9. Are there waterfalls or rapids in a nearby stream? What causes them? Illustrate your explanation with a cross-sectional diagram.

10. Look for these features in any stream: meanders, cut banks, sand and gravel bars, natural levees, rapids, waterfalls, slip-off slopes, ox-bow lakes, river flats, remnants of erosion, and river terraces. At the foot of a narrow valley or gulch, alluvial fans or cone deltas may be seen.

11. By means of the device suggested in No. 3, Chapter III, build up a delta, and cross-section it in order to study its structure.

12. Make a list of the nearest lakes and sloughs, and explain the origin of each basin. Are such basins being filled? Is the water salty? Are any of the lakes swampy around the edges? What does this suggest?

13. Are there any swamps in your district? How have they been formed? Do they have water in them throughout the year? What kind of swamps are they? Were they once lakes?

CHAPTER VI

* * *

PLAINS, PLATEAUS AND DESERTS

57. **Plains.**—A **marine plain** is one which is covered by shallow water. Some have been formed by waves cutting the shore and depositing the waste off shore (Fig. 61). The chalk cliffs near Dover, England, have been cut by the waves; the beach is part of a marine plain formed of material washed from the cliffs. Others may have their origin in bays which are in the process of being filled in, deltas in the making, and salt marshes of estuaries. Marine plains are generally smooth, as depressions have been filled with sediments (sand and mud).

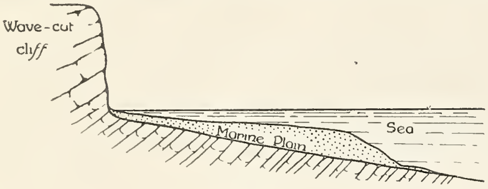

FIG. 61

Diagram to show a marine plain in the process of formation; debris washed from the cliff is carried out by the undertow and dropped; upon uplift, it will become a coastal plain.

Continental shelves are marine plains. Along the Atlantic Coast of North America the marine plain is from 50 to 100 miles wide. Such a plain is considered part of the continent, and hence the sea covering it is said to be an **epicontinental sea** (Fig. 61).

Coastal plains are formed from marine plains by uplift of the shoreline. These form level, sandy stretches of land which may be swampy or dotted with shallow lakes. Rivers which flow over such a plain will be sluggish. Florida is part of a coastal plain which stretches from New Jersey to the mouth of the Rio Grande River. The sediments of the coastal plain are soft and easily eroded, so that they are soon at a lower level than the resistant rocks of the old land; therefore where the streams pass from the old land to the coastal plain, rapids and waterfalls will be formed. Such a line of falls is called a **fall-line.** Some large cities, such as Philadelphia and Washington, are located on a fall-line. This makes good sites for cities; for it is as far as water traffic can progress, and hence reshipment of goods is necessary. Parts of Vancouver are on a coastal plain; Paris is on a similar plain.

The Great Plains, lying between the mountains of Eastern and Western North America, have been at times part of an old sea bottom, which is now elevated in places several thousand feet above sea level. For the most part it is mantled with glacial drift, lake plains, and other deposits.

58. **Lake Plains.**—It was noted above that lakes act as settling basins for sediments carried into them by rivers and streams. The bottom of a lake will have its irregularities of surface filled with sediments, and therefore will be comparatively smooth. Now, if for some reason a lake dried up or was drained, its bottom would be a level plain. Such is the origin of many level stretches of land.

The Red River Valley Plain, which covers part of southern Manitoba, North Dakota, and Minnesota, was once the bottom of a lake called Lake Agassiz. This lake was larger than the combined area of the present Great Lakes. It was formed by the melting of ice during the Ice Age. These plains are so level that one can travel for miles without going through a vertical distance of more than 20 feet. They are well suited to agriculture.

The Great Lakes Plains are the bottom of Lake Iroquois, another glacial lake of which Lake Ontario is the remnant. These plains extend along the shores of Lake Ontario.

Similar plains, found on the prairies and in the mountains of Western Canada, probably had their origin in lake bottoms. The plains at Edmonton and Regina, for example, are the bottoms of glacial lakes.

The Great Basin, part of which is occupied by Great Salt Lake, is a plain formed by the drying up of Lake Bonneville, an old glacial lake.

Plains formed by rivers, viz., flood plains (page 54), delta plains (page 55), and alluvial fan plains (Page 56), have been considered. To all these various plains might be added the tundra, which merely is a plain having a cooler climate. The tundra is a plain formed by denudation; it is a peneplain.

59. **Prairie Plains.**—Plains may or may not be covered by forest. Prairie plains are unforested, a condition due to either drought or fire. They are found principally in Central North America, Brazil, and Argentina. These plains receive enough moisture to bear grasses and crops. The strata of these prairies lie practically horizontal; if they were tilted, the plains would soon be eroded into ridges and valleys (Figs. 1, 41, 43).

60. **Prairie Levels.**—In Western Canada the prairie region is triangular in shape; the three sides are the international boundary on the south, the edge of the forest region running from

Manitoba to about Edmonton on the north-east, and the foothills of the Rocky Mountains on the west (Fig. 62).

This triangle of prairie lands falls into three **levels** or **steppes.** The first and lowest level or prairie steppe is the most eastern and comprises the Red River Valley, the old bottom of Lake Agassiz. The elevation of this steppe is from 700 to 800 feet above sea level. Riding, Duck, and Porcupine Mountains, running northwest of Brandon, form the boundary between this and the second prairie steppe.

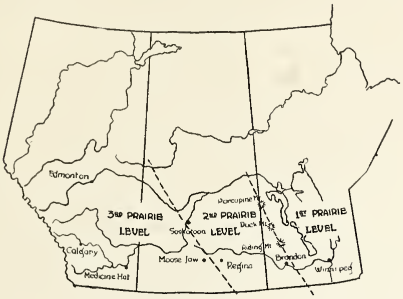

FIG. 62

The prairie steppes or levels; for a cross-section refer to Fig. 93

The second prairie steppe extends from these mountains on the east to the Missouri Coteau on the west. This Coteau is a range of hills extending from the international boundary, passing in a northwesterly direction through Moose Jaw and north of there, gradually diminishing in height toward the north and merging with the prairie.

The third prairie steppe extends from the Coteau to the foothills of the Rockies. In elevation it varies from about 2,000 feet on the east to about 4,000 feet on the west.

These steppes are well defined in the south, but the escarpments diminish in height to the north, and the steppes as individuals lose their identity. None of these three prairie steppes is a level surface, as each has hills and deep valleys; but each does contain large flat areas.

61. **Plateaus.**—A **plateau** is a plain which has been elevated along with mountains by a mountain-building movement. As a result plateaus are found on either side or both of mountain ranges. The strata of plateaus are typically horizontal, but may be tilted in varying degrees. The elevation of a plateau varies a great deal, ranging from 2,000 or 3,000 feet, as in the Alleghany Plateau of Eastern United States, to that of the Plateau of Tibet, which is 15,000 feet above sea level.

62. **Erosion of a Plateau.**—This proceeds like the erosion of a plain, but more slowly; for the rocks are generally harder, and the climate drier. As plateaus are higher than plains, more material must be removed to wear the land down to base level, i.e., to make a peneplain of it.

In youth the plateau has flat topped divides, deep gorges, and canyons. For example, the Grand Canyon of Colorado has steep sides, and rapids and waterfalls are common. In maturity the valleys widen out, and in old age the valley is flat again, i.e., it is a peneplain.

As erosion of a plateau in an arid climate proceeds, here and there will be formed flat, table-like prominences faced by cliffs. The capping rock (it may be lava or sandstone, or some other rock) of such a hill or **mesa** is more resistant than that which once surrounded it. Therefore it wears away more slowly, and, as it protects the underlying rocks, it is left as a hill (Fig. 42). The strata of a mesa are generally horizontal. On account of the prevalence of these structures on a plateau, plateaus are sometimes called table lands. Small mesas are called **buttes** (Fig. 1).

In moist climates weathering and erosion are more rapid, resulting in rounded hills instead of flat-topped mesas and buttes.

63. **Deserts.**—These are popularly thought of as regions of sand with little rainfall. But the main feature of a desert is that it supports few forms of life; the cold ice-covered region of Antarctica is as much a desert as the Sahara.

The hot deserts are not completely sand covered. The surface of the Sahara is only one-ninth sand, and that of the Arabian Desert is one-third sand. They do have rainfall, but it is very scant. One of the driest deserts is in Peru; there seven years have elapsed between falls of rain or other moisture.

When rain does fall in these deserts, it runs off the surface quickly, for there is not enough vegetation to hold it; therefore the streams are intermittent, flowing after rains or in spring. Some of the streams gradually disappear as water sinks into the sand; other streams may be part of an **inland drainage system** like the Caspian Sea, Dead Sea, and Aral Sea. These seas (really large lakes) have no outlets, but a constant level is maintained by evaporation, and, as a result, the water is salty. The waters of some rivers which flow across deserts (like the Blue Nile) may reach the ocean. Sounding Creek, which flows near Youngstown, has several lakes in its channel, but no water in it reaches the sea. It is an inland drainage system.

64. **Erosion of Hot Desert Regions.**—This is accomplished chiefly by changes in temperature

and the scouring action of the wind and its load. Deserts are hot in the daytime and cold at night. This causes rocks to disintegrate rapidly, for stresses and strains are set up among the constituent minerals, which expand and contract at different rates. But more important than this is the action of the wind. Even a breeze will roll sand grains along the surface causing them to rub together, thus reducing one another to dust. Furthermore, as the sand grains are moved by a stronger wind, they wear away stronger rock, thus producing more sand and dust. Fantastic shapes may thus be carved by the wind (Fig. 35). With a high wind severe sand storms may result, and the dust be carried long distances before being deposited. Prevailing winds have built up deposits of this dust. China, for example, has large deposits of this soil, called **loess;** there are also loess soils in places along the Mississippi River. The process of removing small rock particles by wind is called **deflation.**

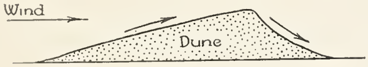

FIG. 63

Section of a sand dune; the arrow gives the wind direction.

65. **Sand Dunes.**—The drifting sand collects in dunes. Some obstruction, such as a rock, halts the progress of the sand, and this may be the beginning of a dune. If the wind blows prevailingly in one direction, dunes will be crescentic in shape, the horns of the crescent pointing in the direction in which the wind is blowing. The slope of the dune is gradual on its windward side, and steep on the lee side (Fig. 63). Sand dunes are also formed along the shores of seas and lakes and in dry river beds. The largest dune area in Europe is along the Bay of Biscay in Western France. The Great Lakes have many dunes. One of these at the southern end of Lake Michigan is several hundred feet high. It is known as "Creeping Joe" from its slow rate of advance.

Sand dunes move or migrate slowly with the wind. Sand grains are rolled up the windward slope and deposited on the leeward side (Fig. 63), and the dune moves by a slow rotary motion. This migration of sand can be very destructive, for if buildings and vegetation lie in its path, the dune buries them. Not only is vegetation destroyed, but land also is rendered unfit for cultivation after the dune has passed. The progress of dunes can be halted by the skilful planting of vegetation; this is done in France, Belgium, Holland, Germany and other countries of Europe. Thus in deserts the lack of vegetation may be due not only to scanty precipitation but also to the shifting of sand dunes.

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Questions:

1. (a) Define: marine plain, epicontinental sea.
   (b) Give four ways in which marine plains may form.
   (c) How can wave action produce a marine plain? Illustrate by a diagram.
   (d) How is a coastal plain formed?
   (e) Where is a fall-line developed? How?
   (f) In what ages was the site of your present abode on a marine plain?

2. (a) How is a lake plain formed?
   (b) Where is the largest lake plain in North America?
   (c) How do you account for the plain at Edmonton?
   (d) Name four other kinds of plains in addition to marine, coastal, and lake plains.

3. (a) Give three features of a prairie plain.
   (b) Sketch on a map of the prairie provinces the positions of the three prairie steppes or levels and the names of the physical features that form the boundaries between them.
   (c) Why are prairie plains treeless?

4. (a) What is a plateau? Where are plateaus found? In what attitude are the strata of a plateau?
   (b) What is the altitude of a plateau?
   (c) Give three reasons why it takes longer for a pleateau to be worn down to base level than for a plain.
   (d) How are mesas and buttes formed?
   (e) Draw a diagram of a mesa or butte so as to illustrate the structure of it.

5. (a) What is the distinguishing feature of any desert?
   (b) Give three other features of hot deserts.
   (c) Why does rainfall run off rapidly in hot deserts?

(d) Where is Sounding Creek? What feature has it and the Volga River in common?

(e) Explain clearly the action of wind and changes in temperature in the erosion of hot deserts.

6. (a) Draw a cross-section of a sand dune.

(b) Draw a diagram of a crescentic sand dune, and indicate on it the direction of the wind.

(c) Explain how sand dunes migrate. How can this movement be arrested?

(d) Name four localities favorable for the development of sand dunes.

(e) Write a note on the destructiveness of sand dunes.

(f) Define: loess, deflation.

(g) What are the two factors that cause lack of vegetation in deserts.

(h) What is the origin of the sand hills which are found at numerous places in Alberta and Saskatchewan? Where did the sand come from? Describe the sand hills nearest to your home—if there are any.

Suggested Activities:

1. List as much evidence as can be found that Alberta has at times been sea bottom. The presence of limestone and shale with marine fossils suggest this. Is such evidence to be found in your district?

2. What features of a plain can be found in parts of Alberta? Are the strata flat-lying? Is it forested? What would be the topography if the strata were inclined? Draw a cross-section to show the result of this inclination of strata. How was the plain formed? Was it once sea bottom or was it levelled off by the action of glaciers?

3. Can the plains of Alberta be called a plateau? Are there any mesas or buttes in your locality? Are there any other evidences of the erosion of strata? Look for outcrops of strata in any hills, especially on the steeper slopes. These hills may be classed as buttes or mesas.

4. Can you find any examples of wind erosion such as hoodoos or furrows or sand hills? Note how the open ground is swept bare of loose particles after a severe wind. This is deflation.

5. Are there any sand dunes in your district? Where is the closest dune area? What is the source of the sand? Is it beach sand from an old glacial lake, sand from a moraine, or sand from the disintegration of bed rock? Are the dunes moving or stationary? What evidence is there for your conclusion?

6. Secure a sample of sand from a sand dune and examine it under a magnifying glass or microscope. Compare the rounding of these grains with some obtained from the bed of a stream. Obtain the larger sand grains for examination by mixing with water, stirring, and decanting. The sand grains from the dune will be more rounded than those from the stream; the farther the sand has travelled, the more the particles will be rounded.

CHAPTER VII

* * *

VOLCANOES, HOT SPRINGS AND EARTHQUAKES

66. **Volcanoes.**—A volcano is a conical peak topped by a cup-shaped hollow, the **crater.** From the crater down to the interior of the earth a fissure or pipe extends, along which ejected materials move upwards. These materials after discharge from the crater may be in a solid, liquid, or gaseous state. The hill itself is made up of the ejected materials which have fallen or solidified near the vent (Fig. 64). Volcanoes are not mountains, even though they are sometimes associated with mountains; for they do not involve dislocation of strata, the principal characteristic of mountains.

67. **Volcanic Materials.**—These are ejected in three forms: solid, liquid, and gaseous. The solid forms are **volcanic bombs, lapilli, ash,** and **dust.** Bombs vary in size from a few inches to several feet in diameter. They are masses of lava which were blown out of the volcano either in a solid or liquid form, but hardened in the air, taking on an elliptical shape as they rotated. **Lapilli** are smaller fragments of lava from the size of a pea to that of a walnut. Still smaller fragments are **ash,** and the finest particles are **dust.** Beds of ash and dust may consolidate to form **volcanic tuff.** In general these materials are called **cinders** and **ash.** These solid materials form more or less stratified layers in the cone, and together are called **agglomerate.**

The liquid rock, **lava,** may in an eruption overflow the crater or burst from a fissure in the side of the cone. Lava contains much steam, which expands, forming cavities in the rock.

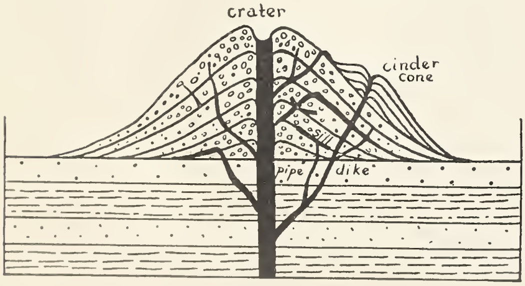

FIG. 64

Diagram to illustrate the structure of a volcanic cone; the sills and dikes help to bind together the layers of cinders and lava.

Pumice is a type of hardened lava which contains so many cavities that it is frothy in appearance and so light that it will float. The lava which has cooled on the slopes of the cone, together with the lava which has been forced into fissures in the cone in the form of dikes, binds the whole structure together (Fig. 64). Lava is of two main types, one of which is thick and viscous, and the other thin and mobile.

Enormous quantities of water vapour are discharged along with sulphurous fumes and other gases. The apparent discharge of flames from a volcano is but the reflection of molten lava in the crater on the clouds of condensing steam rising from it. In an eruption gases are always given off, and generally either solids or liquids are ejected with them, though sometimes all three may be present.

68. **Types of Volcanoes.**—Volcanoes fall into three types with respect to their mode of eruption. These are: (1) explosive type, (2) quiet type, (3) intermediate type. The principal features of each are best illustrated by recently active volcanoes.

(1) **Explosive type.**—The classic example of this type is the island volcano Krakatoa, situated in Sunda Strait in the East Indies, between the islands of Java and Sumatra. In 1883 this volcano gave evidence of its resumption of activity by a series of earth tremors. Then followed a succession of terrific explosions which blew away a greater part of the island and strewed the sea with pumice. More than one cubic mile of rock, it is estimated, was blown away (Fig. 65). The explosions were heard over 150 miles away. Dust was blown seventeen miles high in the air; it fell on ships 1,600 miles away, and caused brilliant sunsets for months afterwards all over the earth. Tsunamis, over 100 feet high, destroyed 1,295 villages and towns, killing 36,380 people. Great blocks of stone thirty to fifty tons in weight were carried two or three miles inland, and a large ship was also carried inland a mile and a half and left stranded thirty feet above sea level. This was the greatest manifestation of volcanic activity in modern times.

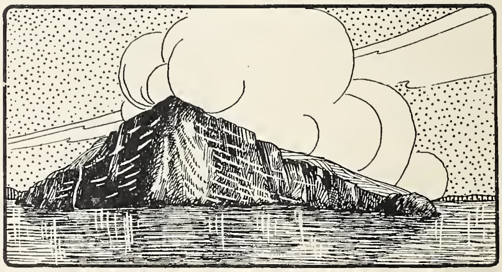

FIG. 65

The chief remaining fragment of Krakatoa after the eruption of 1883; note the stratification of the agglomerate comprising the cone.

In 1902, Mont Pelée on the island of Martinique in the West Indies erupted with a series of violent explosions, which were preceded by the usual local earthquakes. A feature of this outburst was the formation of a mass of incandescent rock particles which rolled down the mountainside to the sea, destroying all life in its path. Of all the 30,000 inhabitants of the town of St. Pierre at the foot of the volcano, only one man, a prisoner in a dungeon, survived, and he owed his life to his incarceration. Another feature of this eruption was the pushing upward of the very viscous and solid lava in the crater in the form of a **spine** to a height of about 1,000 feet above the rim of the crater (Fig. 66). This spine soon crumbled away.

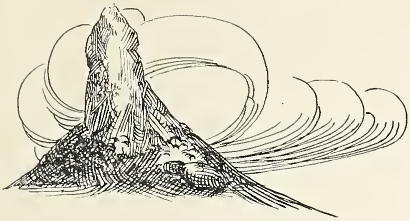

FIG. 66

The spine of Mont Pelee on Martinique.

In this type of volcano the sides are steep, up to forty degrees, the cone being composed chiefly of cinders. The lava is of the viscous type.

(2) **Quiet type.**—The Hawaiian Islands are a group of volcanic cones which have been built up from sea bottom by the eruption of volcanic materials. The cones of these volcanoes were built by eruptions of very thin liquid lava and are, therefore, quite flat and form a plateau on top. The summit of the mountain volcano, Mauna Loa, is flat for several square miles, and the sides do not slope more than seven degrees. This volcano reaches from 16,000 feet below sea level to 14,000 feet above it, a total height of 30,000 feet, which is greater than that of Mount Everest. When this volcano erupts, lava may well up in the crater and overflow it, but more often it emerges from a fissure in the side of the cone some distance from the crater and flows down the slopes. It has flowed as far as thirty miles before cooling.

The crater of Kilauea on the east side of Mauna Loa is about nine miles in circumference. The floor of the crater is a stony crust, and here and there are lakes of liquid lava, red to white hot. Sometimes a lava flow cascades over a cliff into the sea producing a spectacle visible for over 100 miles at sea. Mauna Kea, a third volcano on the same island, is extinct.

While there are no violent explosions during an eruption of this type, yet sometimes the flows of lava cause considerable damage to property. Very little ash and cinders are erupted.

(3) **Intermediate type.**—Most volcanoes are of this type, and of these Vesuvius is the best known (Fig. 67). Vesuvius is built upon the floor of the old crater of Monte Somma, an ancient volcano. This ancient volcano had been dormant so long that its slopes were covered with vineyards and its crater floor was a plain upon which an army at one time had encamped. For several years prior to 79 A.D. earthquakes were numerous in the vicinity; then in that year a series of terrific explosions followed by eruptions of fragmentary material (ashes and cinders) took place. Herculaneum and Pompeii, two cities at the foot of the mountains, were overwhelmed, Pompeii by ash and lapilli from ten to thirty feet deep, and Herculaneum by a mud flow (resulting from condensed water vapour and ash). In the explosions the greater part of Monte Somma was blown away (Fig. 67). Every two or three centuries since then eruptions have taken place, and the present cone of Vesuvius has been built upon the floor of the old crater. Flows of lava and layers of ash and cinders make up the cone, the sides of which slope at angles of from twenty-six to forty degrees. The whole mass of cinders and lava is bound together by numerous dikes. The last eruption took place in 1906. During this eruption lava issued forth as well as clouds of dust and ashes; the latter settled on the roofs of houses to such a depth that it caused them to collapse.

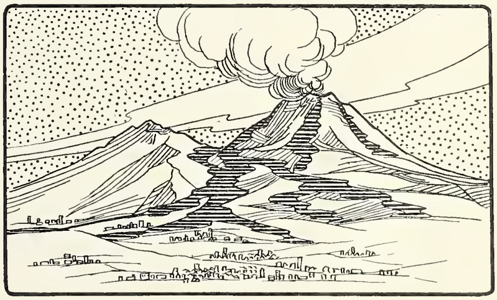

FIG. 67

Vesuvius as seen from Naples; the remnant of the cone of Monte Somma is on the left.

The intermediate type of volcano resembles both the quiet and explosive types in the nature of the eruption and in the products. Mount Etna in Sicily, and Stromboli, the "Lighthouse of the Mediterranean" (so-called because of the flashes of its explosions which occur from

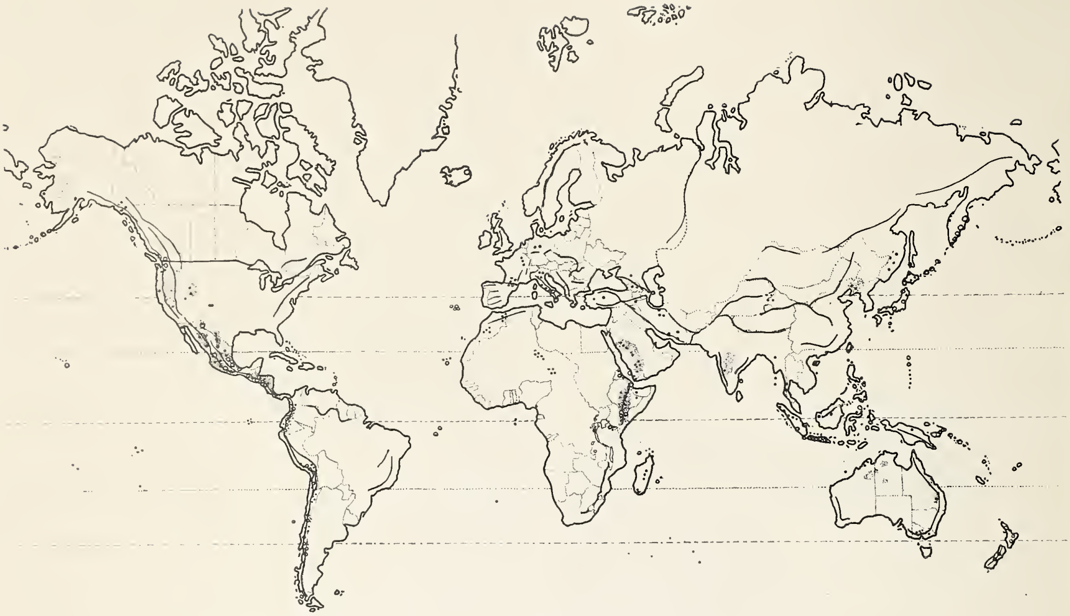

FIG. 68

Map of the World to show volcanic and earthquake zones and principal mountain systems.
(Volcanoes are shown by dots, earthquake zones are stippled, and mountain systems are represented by black lines).

one to ten minutes apart), are other examples of this group.

69. **Volcanic Belts.**—Most of the volcanoes of the earth's surface lie in two belts or zones (Fig. 68). One of these completely encircles the Pacific Ocean taking in some of the peaks of the Andes of South America, western United States, Aleutian Islands, Japan, and Philippine Islands. Numerous islands of the Pacific are of volcanic origin and are included in this zone. The other zone is a tropical belt more or less paralleling the equator, in which are the volcanoes of Central America, West Indies, Azores, Canary Islands, Mediterranean Sea, Asia Minor, Northern India, and East Indies. Vesuvius and Krakatoa are in this belt. These zones are lines of weakness in the earth's crust. It is to be noted that they almost coincide with the mountain ranges and earthquake zones (Fig. 68).

Canada has no active volcanoes, but there is much evidence of volcanic action in the past in certain parts. Mount Royal at Montreal is the remnant of one of several volcanoes which were once active in that region. In Alberta beds of volcanic ash are common in strata, proving that active volcanoes were near; in the Crowsnest Pass there are thick beds of lava which geologists have named the **Crowsnest Volcanics.** These are a rock formation lying between the Blairmore sandstone and the Alberta shales.

70. **Cause of Volcanoes.** — It was formerly thought that surface water seeping into the earth to the heated rock far below caused the explosion. It was observed that Kilauea frequently erupts in the rainy season, and that Vesuvius and Etna have erupted most often in winter and spring—times when there is most rain. But the general opinion now is that though this factor may cause some eruptions, their real origin lies in mountain-building movements.

In the preliminary stages of mountain building, the surface rocks, many miles thick, are arched to form a huge anticline. The hot rocks

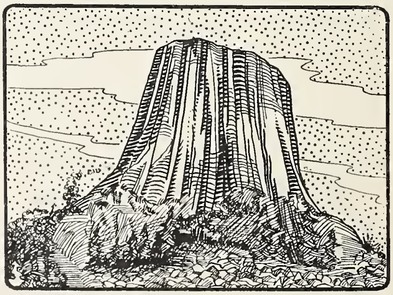

FIG. 69

Mato Tepee, Devil's Tower, a volcanic neck in Wyoming; it shows almost vertical columnar structure of the cooled lava which filled the pipe or feeder; all other parts of the cone have been removed by denudation.

under this anticline at first could not melt; for the pressure was so great, that they could not expand. But as the anticline developed, there was room for their expansion; they melted, therefore, and then forced their way to the surface along fault planes and fissures. This lava does not come from very far below the surface, for it is of the same composition and density as surface rocks. Moreover, volcanoes have not a common reservoir, for volcanoes only a few miles apart may emit a lava of two different types.

71. **Life History of a Volcano.**—Lava or cinders or both are discharged from the fissure and pile up around the vent forming the cone. The height to which a volcano will grow depends on the type and the length of its life. Some are active for a short time only and then become extinct; others may exist for a long time, having short periods of activity alternating with long periods of quiescence. Sometimes the vent becomes plugged, so that materials are ejected from fissures in the sides, and thus subsidiary cones or **cinder cones** (Fig. 64) are built up on the sides of the main cone.

No matter how long the volcano has existed, there comes a time when the forces which caused it cease to operate, and it becomes extinct. Extinction may come about by a violent explosion, as with Krakatoa, or the lava may simply drain away and the crater collapse to form a **caldera,** as in Mount Mazama, Washington (Figs. 56, 57). But more often the volcano quietly dies and is destroyed by denudation.

One of the first signs of extinction is the formation of a lake in the crater. Later this lake is drained as the rim of the crater is worn away. The materials making up the cone are porous and loosely held together; moreover, contraction of the hot rock on cooling has produced many cracks. Air and water penetrate, and the cone is therefore readily attacked by the agents of weathering and erosion. Its slopes are gullied and worn away until all that is left is the column of solidified lava that filled the vent. This is known as **volcanic neck** (Fig. 69). When these volcanic necks wear down to the level of the land they are **volcanic plugs.** The **blue clay,** the source rock of diamonds in South Africa, is the decayed lava of such volcanic plugs.

72. **Fissure Eruptions.** — Sometimes lava pours forth from a fissure several miles in length, and spreads over the land by repeated eruptions in depths of even thousands of feet, and covers thousands of square miles. Parts of the states of Oregon, Idaho, and Washington are covered by lava fields 200,000 square miles in area (Columbia and Snake River lava plateaus) (Fig. 70). Several eruptions have levelled off the land by filling up the valleys. In India there is another lava field almost as great in extent. Fissure eruptions have been by no means rare in the earth's history. They have occurred extensively in Europe, Asia, Africa, South America, and other places. Yellowstone Park in Wyoming has a lava field erupted only fairly recently, for hot springs and geysers abound there. Large areas of the Canadian or Precambrian shield and British Columbia have been covered by lava.

The only fissure eruption that has occurred in historic times broke out in Iceland in 1783. Lava welled up out of a crack in the earth twelve miles in length and flowed outwards on both sides. Some ash was also thrown out. As activity lessened, the fissure was sealed up in places, and small cones developed at the open places.

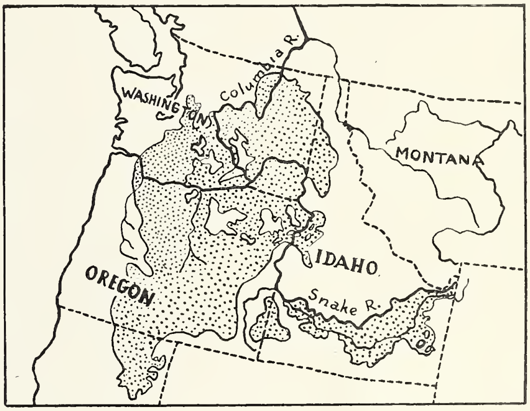

FIG. 70

Extent of the Columbia and Snake River lava fields in northwestern United States; the fields are named after the principal rivers which flow through them.

Soils formed from lava are very fertile and are extensively cultivated wherever climatic conditions are suitable. The decomposed lava of India yields enormous quantities of wheat and cotton; the Columbia lava field grows much wheat.

73. **Decline of Volcanic Activity.**—With the decline of volcanic activity the fissure will gradusually close; but, even after lava and cinders are no longer ejected, steam and other gases will continue to rise from the crater and from fissures in the cone. Such fissures emitting gases are called **fumeroles.** Following this stage comes an interval in which hot water is given off, and then, just before complete extinction, there is the period of warm springs, mineral springs, and carbon dioxide. Yellowstone Park is at the hot spring stage.

74. **Hot Springs.** — The heated water rises along fault planes from bodies of hot rock close

to the surface. This heated rock may be a mass of lava beneath the surface, or, if no volcanoes are present in the area, then the source of heat might be a batholith which lies close to the surface. Other possible sources of heat are: (1) the friction of moving rock masses when mountains are being raised, and the heat has been kept in as rock is a poor conductor of heat; (2) chemical action in the rocks; (3) heat present in the earth's interior.

Hot springs are located along fault planes generally, and may have cold springs close by. The temperature may vary up to boiling point. The Upper Hot Springs at Banff have a temperature of 118 degrees Fahrenheit, and the lower springs at the Cave and Basin have a temperature of 94 degrees Fahrenheit. The water of these springs is ground water which has seeped to great depth, become heated, and risen to the surface. It has been observed that the hottest springs are situated along fault planes, where the greatest heat would be developed.

75. **Geysers.**—A geyser is a hot spring which erupts at intervals for a short time. Some geysers spout at regular intervals, but others are erratic. The force behind the eruption is the great steam pressure developed at depth. The column of water in the narrow neck is heated at the bottom to a temperature above boiling point. This water would change to steam were it not for the weight of water above, which prevents it from expanding into the gaseous state. The bottom temperature, however, finally becomes so great, that it is able to vapourize the water there and to lift out the column of water above it. After the eruption of water and steam, the neck fills up with water again, some of the ejected water running back in, and the rest seeping in through cracks. This water is again heated, and the eruption is repeated. Old Faithful, a geyser in Yellowstone Park, erupts about every sixty-five minutes, and each eruption lasts about four minutes. It throws water to a height of about 100 feet, and some 3,000 barrels of it are ejected on each occasion.

76. **Mud Volcanoes or Paint Pots.**—These are cones built up by very hot steam or gases escaping through a layer of mud. These structures have a small crater at the top and vary in height from a few feet to several hundred. Their activity may be continuous or intermittent. Paint pots owe their name to the colour of the mud, which may be reddish or some other colour due to the iron or other minerals present.

77. **Mineral Deposits.**—Hot water has greater solvent power than cold, and is able therefore to dissolve more mineral matter from the rocks and to carry it in solution. As the hot water cools, much of this dissolved material will be deposited, particularly around the vent where cup-shaped structures and terraces are built up. **Tufa** is a deposit of lime (calcium carbonate) which is porous and of a white or creamy colour, and may be deposited by hot or cold springs. Geysers and hot springs may build up a deposit of silica called **siliceous sinter** or **geyserite,** which are varieties of opal.

As the hot waters ascend, they might, on cooling, deposit some of the mineral matter in cracks and fissures in the rock to form mineral veins. If there are salts of metals present, mineral veins containing gold, silver, copper, etc., may result, and these might form an ore deposit rich enough to be profitably worked. Many valuable ore deposits are found along or close to fault planes, for there the fracturing has produced many cracks and cavities in which minerals could be deposited.

78. **Causes of Earthquakes.** — Earthquakes and volcanoes are often associated. The eruption of Vesuvius in 79 A.D. (page 67) was preceded for several years by earthquakes. The shocks due to earthquakes are generally caused by explosion or by the upward pressure of lava, and produce only a local disturbance around the vent. These might be called **volcanic earthquakes.**

Other earthquakes are not associated with volcanoes, and it is these that cause great destruction. They have originated deep in the earth's crust, and along a line possibly many miles in length. These shocks are caused by some displacement of the earths' crust and will be registered long distances away. This displacement of the rocks may originate in the adjustments that the crust is making because of denudation or mountain-building. The rocks are faulted and slip along fault planes. In faulting, these rocks bend as far as possible and then break under the strain. The fractured ends vibrate as they snap back into positions of no strain, and these vibrations travel through the earth and constitute a **tectonic earthquake.** The actual place of fracture is the **focus,** and the point directly above it on the earth's surface is the **epicentrum.** The epicentrum might be a path rather than a point, for the fault along which the displacement takes place is sometimes miles in length.

Earthquakes occur chiefly in two belts, and these belts practically coincide with the volcanic belts (Fig. 68).

79. **Effects.** — The actual movement of the particles which transfer the earthquake wave may measure only a fraction of an inch, but the suddenness of the shock is sometimes sufficient to topple or rock buildings or to shake them off their foundations, cause landslides, produce fissures in the ground, and raise or lower the land

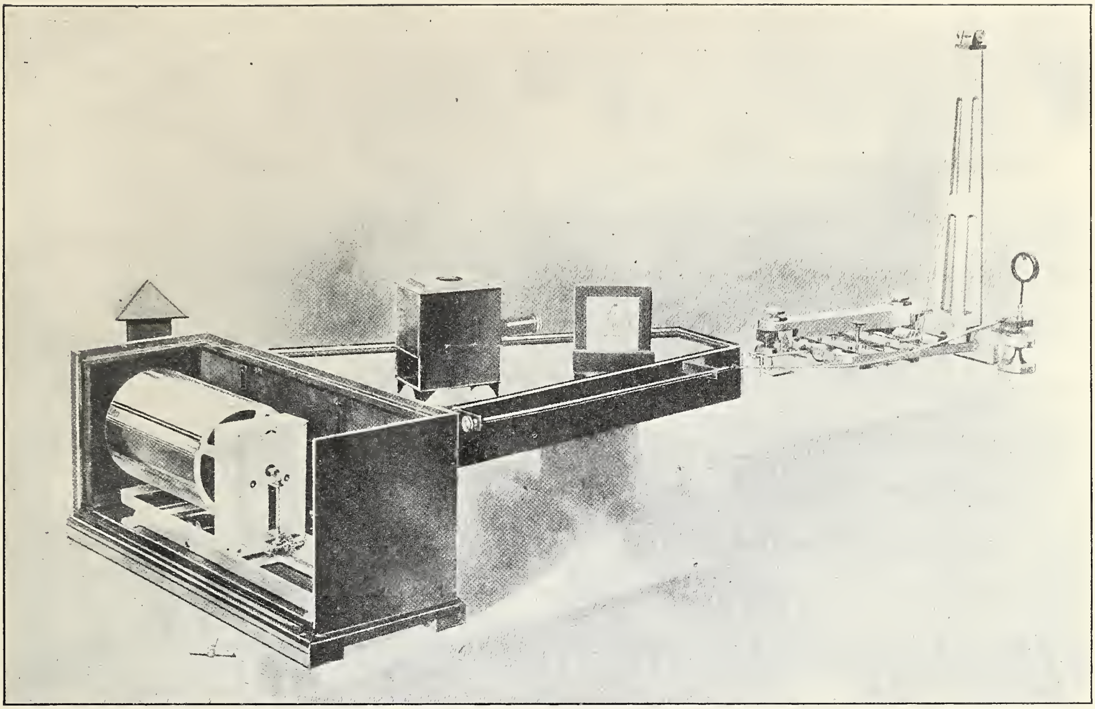

FIG. 71

Milne-Shaw Horizontal Pendulum Seismograph at Victoria, B.C.; cases have been removed to show working parts.

many feet. It is of interest to note that buildings on unconsolidated material like sand and clay suffer more than similar structures on bedrock such as limestone. Movements may be horizontal or vertical. Vertical movements produce a steep cliff called a **fault scarp.** In the New Zealand earthquake of 1855 the fault scarp, nine feet high in places, was traceable for ninety miles. In the sea bottom, scarps as great as 2,000 feet have been measured.

The Lisbon earthquake of 1755 was one of the world's greatest. 60,000 people perished in six minutes. Fissures were opened in the mountains, producing landslides; they were also opened up in the harbour, swallowing up ships and a pier upon which a large number of people had sought refuge. Buildings on clay ground were shattered, but those on limestone were not. Tsunamis rushed over the land raising the sea level fifty feet or more. The shocks were felt in the Alps, Ireland, and even in the Great Lakes region of North America.

There are two kinds of waves produced by earthquakes—those that pass straight through the earth at a rate of six and a quarter miles a second and those that travel along the earth's crust at two miles a second. By noting the time interval between the arrival of these two types of waves one can estimate the distance to the epicentrum, and also from the records its general direction. The records from three seismographic stations are sufficient to locate accurately the epicentrum of the disturbance.

80. **Recording and Locating Earthquakes.** — Earthquake tremors are recorded by a machine called a **seismograph.** One type of machine has two or three heavy pendulums suspended in such a way as to record two or three movements at right angles to each other, viz., north and south, east and west, and up and down (this last is omitted in some seismographs). The end of each pendulum is fitted with a fine point or pen, which makes marks on a sheet of smoked paper. The smoked paper is wrapped about a drum, which is rotated by clockwork. The pillars that support the pendulums and the foundations of the drum are very solid, but the pendulums themselves hang freely from the pillars. Their weight keeps them stationary for a long time during tremors of the earth's crust, while the pillars and foundations of the seismograph

vibrate. Vibrations of the drum move the paper beneath the points, and thus a record of these movements, a **seismogram,** is traced on the paper (to an observer the pendulums appear to move). As seismographs are very delicate instruments, they detect earthquake tremors that would otherwise pass unnoticed. A seismogram consists of a series of zig-zag lines crossing a central line on the paper, and the amplitude of each curve is a record of the amplitude of each vibration of the earthquake shock. The movements of the earth's crust are magnified by the pendulums, and are not as great as are shown on the seismogram.

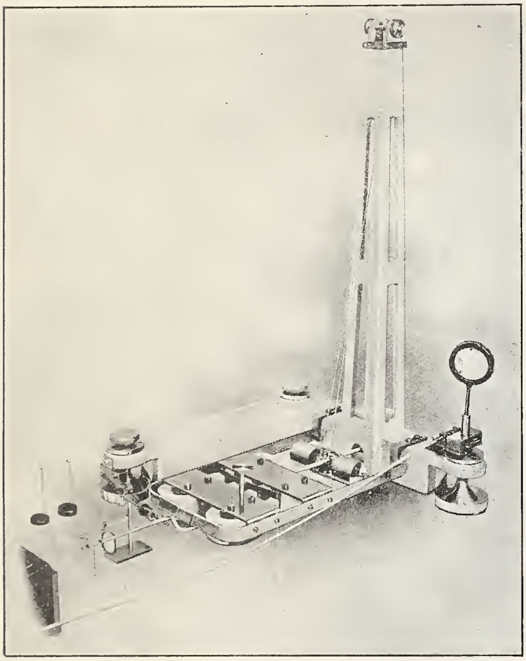

FIG. 72

Enlarged view of the tower and pendulum of the seismograph.

In another type of seismograph, the seismogram is produced by the action of a beam of light on paper sensitive to light (Figs. 71, 72). Instead of being vertical a pendulum is supported so that it moves in a horizontal plane, that is, a plane parallel to the earth's surface. The axis of the pendulum is at the bottom of the tower on the right, and the other point of support is near the cylindrical weights where the pendulum boom is suspended from the top of the tower (Fig. 72). Near the axis of the pendulum are the weights, and at the free (registering) end is a mechanical connection with a swinging mirror. The axis rests on a concrete mass fixed in the earth, and so vibrates with the earth's crust when it is disturbed. During this motion the weights remain practically stationary and act as the fulcrum of a lever (here the pendulum boom). As the axis moves or vibrates, the other free end of the boom moves in the opposite direction. This gives it a wide swing, greatly magnifying the amplitude of vibration of the earthquake waves. A damping device, consisting largely of permanent magnets, prevents the swing from becoming unstable or erratic. The mirror attached to the free end of the boom is swung and reflects light from a lamp, again magnifying the motion. The reflected light falls on the sensitized paper (which is wound on a drum operated by clockwork), and gives an accurate record of the earthquake vibrations (Fig. 71). The motions of the earth's crust are greatly magnified by the machine, the total magnification being from 200 to 250 times that of the earth waves. The whole apparatus is enclosed in cases, and it is about seven feet long. (Cases are removed in the figures in order to show the working parts). This type is in use in the Department of Mines Observatory at Victoria, British Columbia.

* * *

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Questions:

1. (a) Give four important features of a volcano.
   (b) Why are volcanoes not classed as mountains?
   (c) Enumerate and distinguish the solid materials ejected by a volcano.
   (d) Do volcanoes give off flames? Explain.
2. (a) What are the different types of volcano? Give three distinguishing features of each.
   (b) Draw a diagram of a volcano and describe its structure.
3. (a) On a map of the world locate the two volcanic belts.
   (b) What evidences of volcanic activity are to be found in Canada? State three instances.
   (c) Briefly explain the cause of volcanoes.
   (d) Describe briefly the stages in the denudation of an extinct volcano.
   (e) How is a cinder cone formed?

4. (a) Describe briefly how a fissure eruption takes place.
   (b) Of what economic importance may be such an eruption?
   (c) Sketch on a map the extent of the Columbia lava field.

5. (a) What is the original source of water in hot springs?
   (b) What are four probable sources of heat in hot springs?
   (c) Where are the hottest springs located in mountains? Why?

6. (a) What is a geyser?
   (b) How is enough pressure built up in a geyser to expel the water?
   (c) What are mud pots or paint pots?
   (d) How are mineral veins formed?

7. (a) What are two causes of volcanic earthquakes?
   (b) What is the cause of tectonic earthquakes?
   (c) Define: focus, epicentrum.
   (d) What are the effects of earthquake waves?
   (e) Describe the two kinds of earthquake waves.
   (f) Where are the two earthquake belts?
   (g) How can the epicentrum be approximately located?
   (h) Describe briefly one type of seismograph.

8. On a map of the world mark the following:
   (a) Volcanic belts (in red hachures);
   (b) Earthquake belts (in blue hachures);
   (c) The location of: Krakatoa, Vesuvius, Mauna Loa, Lisbon, San Francisco, Columbia River, Yellowstone Park, Mount Royal, Blairmore, New Zealand, Mont Pelée.

9. Why do volcanic and earthquake zones practically coincide?

10. Define: pumice, volcanic spine, tufa, siliceous sinter, fault scarp, agglomerate, caldera, blue clay, Crowsnest Volcanics, fumerole, volcanic ash.

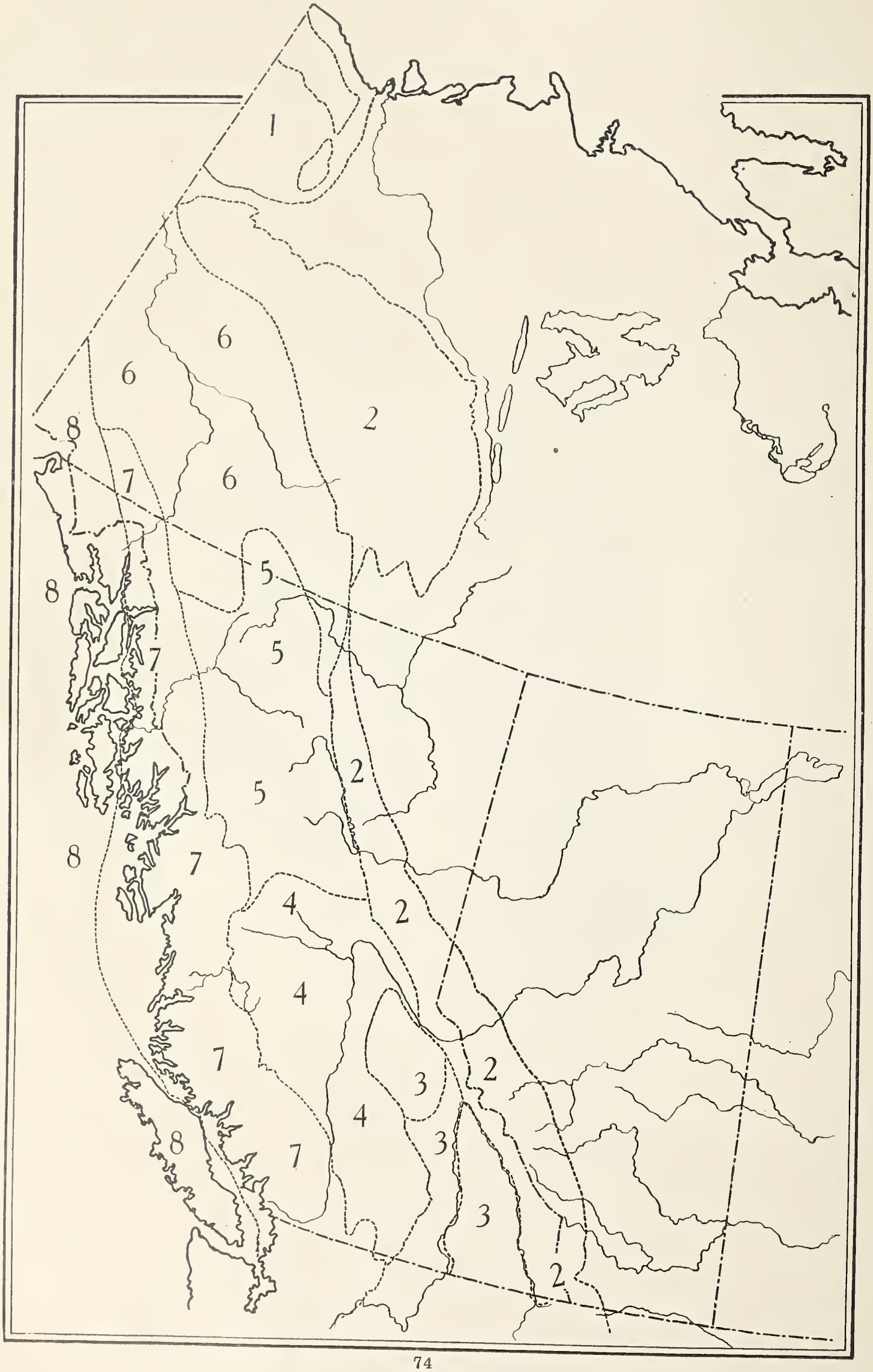
Suggested Activities:

1. Bentonite is considered to be decomposed volcanic ash. There are many seams of it in the Benton, Belly River, Edmonton, and Paskapoo formations. These seams can be recognized by their light colour and soapy feel when wet. Search for such seams in bed rock exposed in your area. The ash was most likely carried by prevailing winds from erupting volcanoes to the northwest.

2. Hot springs occur in the Rocky Mountains at several places. If opportunity presents itself, the positions of the springs should be noted (on the eastern sides of the mountains). Is there a deposit around the hot spring? What is the origin of the deposit? Is the flow of water steady?

3. The principle of the seismograph can be shown by suspending a weight of about one pound from a string 18″ long tied to the arm of a retort stand. The weight represents the pendulum of the seismograph, which does not move during an earthquake. Place a pointer in front of the suspended weight to mark its position. Then grasp the retort stand at top and bottom, and move it rapidly from side to side through a space of about 2". It will be observed that the pendulum remains in the same place just as it does during earthquake vibrations.

4. Has your newspaper reported any earthquakes within the last few days or weeks? Look up the epicenters in an atlas. Are such centers of disturbance on the earthquake zones of Fig. 68?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CHAPTER VIII

* * * *

MOUNTAINS

81. **Introduction.**—The term **mountain** is used rather loosely, being a name applied to any prominent geological structure that rises for some distance above the general level of the land. It has a summit of small area. Mountains sometimes occur singly but more often in groups. Sometimes such elevations are called hills, mesas, or buttes, although there is no apparent reason why they should not be called mountains. The Cypress Hills in southeastern Alberta and southwestern Saskatchewan which rise to an elevation of 4,600 feet, 2,500 feet above the level of the plain, are termed hills. Tunnel Mountain at Banff is but 5,510 feet in elevation, rising only 1,000 feet above the valley, and yet it is called a mountain. Duck Mountain in Manitoba (Fig. 62) rises just 2,500 feet above sea level, and the Riding and Porcupine Mountains are even lower, but still these are "mountains". Thus the term does not really indicate what elevations can be expected. Mountains rising more than 10,000 feet above sea level are considered lofty.

A characteristic of mountains is that the strata are rarely horizontal, and thus they differ from plateaus. Folds and faults of all kinds are found in mountains, so that in many cases their structure is very complicated.

Mountains cover a large part of the earth's surface (Fig. 68). All of the continents have mountain ranges, and Asia in particular has a great many of them.

82. **Names Applied to Units of Mountain Form.**—A mountain **system** is a series of mountains that have been created by the same uplift and form a group. A **cordillera** is a term applied to one or more systems which extend in a long line and parallel other systems. The parallel systems of mountains of Western Canada may then be correctly called cordilleras. These cordilleras are divided into three belts or bands, viz., the Eastern, Central, and Western Belts. The Eastern Belt takes in the Rockies and Arctic Systems; the Central Belt includes the Columbia, Interior, Cassiar, and Yukon Systems; and the Western Belt is made up of the Pacific and Insular Systems. A system is divided into chains called **mountains** or **plateaus,** which are smaller congeries forming more or less of a unit. The Rockies System is composed of the Rocky Mountains, Mackenzie Mountains, and Franklin Mountains; it is the only system extending into Alberta. The Selkirk, Monashee, and Cariboo Mountains make up the Columbia System; the Interior System is composed of the Fraser and Nechako Plateaus, both being the tablelands of worn down mountains. The Pacific System includes the Cascade, Coast, and Bulkley Mountains; and the Insular system, the Vancouver Island and Queen Charlotte Mountains and part of the St. Elias Mountains. The cordilleras of Western Canada are about 400 miles wide in the northern part of British Columbia, and become wider to the north and south. They all have a northwest and southeast trend. Their various belts, systems, etc., are shown in Fig. 73.

FIG. 73

GEOGRAPHIC MOUNTAIN UNITS OF WESTERN CANADA
(as approved by the Geographic Board of Canada)

Systems are numbered 1 to 8. It is recommended that the student color in the various regions according to the following legend:

Eastern Belt—1. Arctic System (blue); 2. Rockies System (red).

Central Belt—3. Columbia System (green); 4. Interior System (orange); 5. Cassiar System (yellow); 6. Yukon (purple).

Western Belt—7. Pacific System (brown); 8. Insular System (grey). Put heavy black lines between the belts.

Mountains and plateaus are further divided into **ranges, groups,** or **plateaus.** If the elevations form a line of summits, they are a range; but if they form a cluster, they are a group. Plateaus are divided into individual units controlled by general elevation or some other feature. The Rocky Mountains are composed of a number of ranges. Some of these are the Livingstone Range of the Crowsnest Pass area, the Highwood Range immediately north of it, the Rundle-Cascade and the Sulphur-Vermilion Ranges at Banff, the Bow Range at Field, the Brazeau and Bighorn Ranges at Nordegg, and at Jasper the Miette and Colin Ranges.

As a range is denuded, it tends to separate into individual units, **mountains** or **mounts,** but the separation may not be complete. Removal of the less resistant rock leaves the harder rock at higher elevations. If these high portions of a mountain are steep and pointed they are **peaks,** but if elongated they are **ridges.** Unequal erosion of the strata may cause a mountain to have two or more peaks. Three Sisters Mountain at Canmore has three peaks, Mount Norquay at Banff has two peaks, and Sulphur Mountain also at Banff has several peaks. The highest peaks in North America are found in the St. Elias Mountains of Alaska and Yukon. The three loftiest are Mount McKinley 20,464 feet, Mt. Logan 19,539 feet, and Mt. St. Elias 18,008 feet above sea level. Mt. Logan is in the Yukon, and hence is the highest mountain in Canada.

Between mountain ranges and systems there are valleys of which certain types are given special names. An **interior basin** is a broad plateau which lies between mountain systems

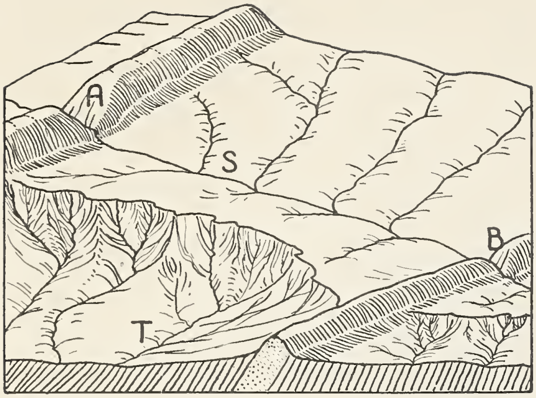

FIG. 74

Diagram showing water gaps; S, the master stream of the region, flows across two resistant ridges having cut water gaps in them at A and B.

and which has no outlet. Great Salt Lake and Caspian Sea occupy parts of such basins. Broad valleys between ranges are called **parks.** The towns of Banff and Jasper are in park land. Many other valleys in the Rockies are parks.

Narrow gorges which cut across ridges and through which water flows are **water gaps** (Fig. 74). They are at right angles to the strike of the bed rock. Water gaps are common in Alberta, for streams leave the mountains through valleys which have an easterly trend, whereas the trend of the Rockies is northwesterly. If for some reason, such as **river piracy,** a stream ceases to use a water gap, the abandoned gorge becomes a **wind gap** (Fig. 75). The stream that captures the water of another is called a **river pirate.**

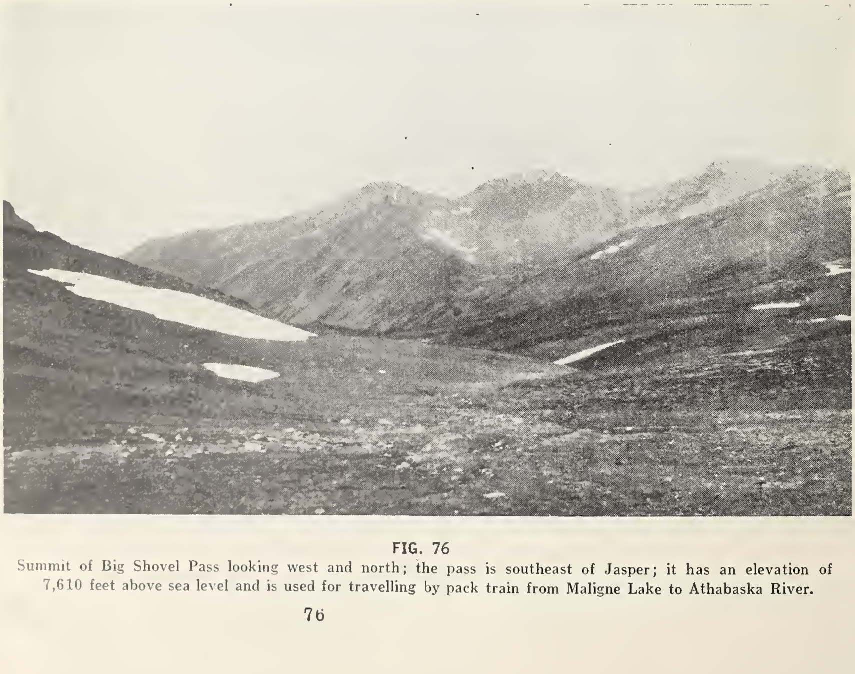

FIG. 76

Summit of Big Shovel Pass looking west and north; the pass is southeast of Jasper; it has an elevation of 7,610 feet above sea level and is used for travelling by pack train from Maligne Lake to Athabaska River.

Most mountains are in the form of a long chain which effectively separate the land on each side except where there are low places or **mountain passes** through which communication is possible (Fig. 76).

Passes generally occur where two streams head together from opposite sides of the mountains or where glaciers have been active. There are three important passes in the Rockies. Of them Yellowhead Pass, west of Jasper, is the lowest, being 3,729 feet above sea level. Within a few miles of this pass is Mt. Robson, 12,972 feet in elevation, the highest peak in the Canadian Rockies. Kicking Horse Pass (on the Great Divide) between Lake Louise and Field is over the continental divide (so called because water runs off it to reach the Pacific and Arctic Oceans, Hudson Bay and the Gulf of

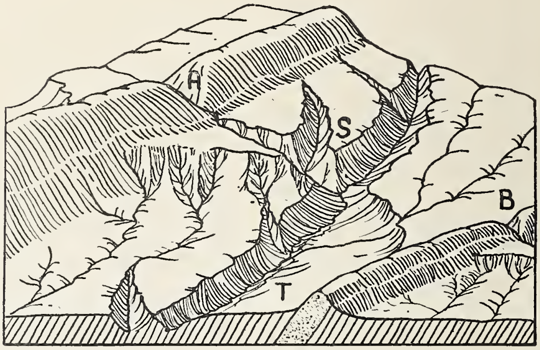

FIG. 75

Diagram showing the same region as in Fig. 74 after river capture; stream T and its tributaries have encroached more and more on the drainage basin of the master stream S, and have finally captured the stream itself; water no longer flows through the notches A and B, which are then known as wind gaps.

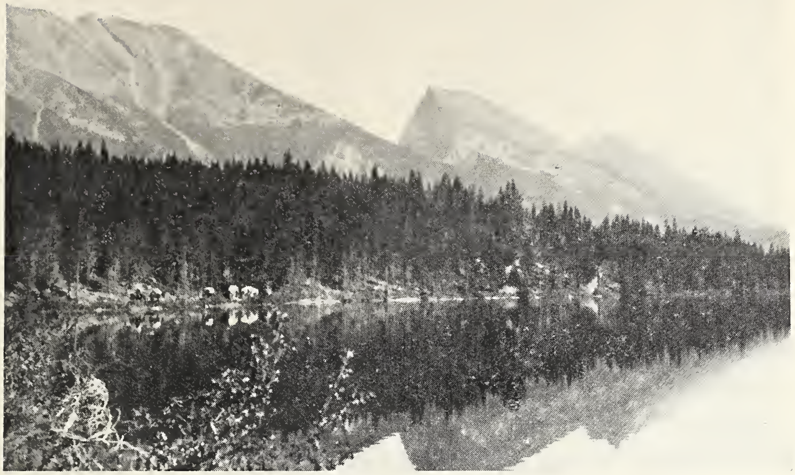

FIG. 77

Block mountains in the Rocky Mountains at Honeymoon Lake near Sunwapta Falls, Jasper Park; the fault blocks dip westward and are composed of Cambrian quartzites; the faulted eastern faces are the steeper.

Mexico) ; it is 5,329 feet above sea level and was carved out by ice. Crowsnest Pass, west of Blairmore, has an elevation of 4,450 feet. In the Rockies south of the international boundary passes are much higher, being 7,000 feet or more. The passes of the Andes Mountains may exceed 12,000 feet in elevation.

83. **Climate of Mountains.**—The temperature of mountains decreases at the rate of about 1° F. for every 300 feet of elevation, so that the temperature on some mountain tops is so low that snow prevails even in summer. The line above which there is perpetual snow is the **snow-line.** It is a line joining points on the earth's surface having an average temperature of about 30° F. At the equator the snow-line is at an elevation of about 16,000 feet, but decreases in elevation towards the poles. In the Alps it is at about 8,500 feet, and in northern Greenland it is at sea level. Its elevation will vary with latitude, precipitation, sunlight, slope, and prevailing winds. Below the snow line there is a zone in which trees will not grow, as the temperature is too low. The line which forms the lower boundary of this zone is the **timber-line.** In the Rockies at Field the timber-line is about 7,000 feet; in northern British Columbia it is at 3,500 feet. Both snow-line and timber-line are lower on the shady side than on the sunny side of a mountain.

The effect of mountains on precipitation is important. When winds blow off large bodies of water, intercepting mountains cause abundant precipitation on the windward side. Having thus lost their moisture, these prevailing winds reach the leeward side as drying winds, and give rise to desert and semi-desert conditions. (p. 19).

84. **The Mountain Belts.** — Mountain systems of the world are distributed in two belts which more or less coincide with the earthquake and volcanic belts (Fig. 68). One belt practically encircles the Pacific. It takes in the Andes Mountains, Coast Ranges of United States and Canada, Aleutian Range, and the mountains of Kamchatka Peninsula, and of the Japanese and Philippine Islands. The other belt extends east and west just north of the equator. Some of the ranges and systems of this zone are Atlas Mountains, Pyrenees, Alps, Carpathians, Caucasus, Elburz, and Himalayas.

Not all mountain ranges border the sea; the Appalachians, Sierra Nevadas, Rockies, Kuenlung Mountains of China, and some other ranges are far inland. In spite of this fact the origin of most of them is in a sea bottom which once existed where the mountains now stand. In these seas sediments accumulated and were later raised to great heights by mountain-building movements.

85. **Causes of Mountains.** — Two main theories have been advanced to explain the origin of mountains. One of these, the contraction theory, was outlined on page 8. There is was observed that the formation of new ranges is due to the efforts of a hard outer shell (the lithosphere) to conform to a shrinking interior, and consequently is thrown into folds or is faulted.

The other explanation involves radio-activity, and is not as simple as the former. All rocks of the earth to a great depth contain radio-active minerals, which constantly give off heat energy. At considerable depths this heat collects until it is sufficient to melt the rock. Then the continents sink into this melted stuff, low enough in places to be invaded by seas. These wide basins or synclines that the seas cover are called **geosynclines**, and the invading sea is an **epicontinental** sea. In these epicontinental seas great thicknesses of sediments accumulate. At the same time, as the rock melts, its expansion may cause the solid crust to crack open in places and extrude great quantities of molten lava. This expansion also arches up the floor of the ocean, and the ends of the arches, pushing against the sides of the continents, crush, fold, or fault the newly formed rocks which have accumulated in the basins. The continents then slip around to the places formerly occupied by oceans. The hot molten rock which was formerly under the continents now loses heat more rapidly. It then solidifies; the continents rise again; and the sedimentary rock, being lighter than the other, is pushed up to form the mountain masses. After this, heat again begins to accumulate, and another cycle of mountain-building is under way. It is thought that this cycle has been repeated at least four times in the earth's history.

86. **Types of Mountains.** — There are four main types of mountains: block, folded, normal, and batholithic.

(1) **Block mountains.** — These are huge blocks of strata which have been faulted by earth movement. They have a monoclinal structure, that is, the strata dip in one direction only, and one block may partly over-ride the one next to it, thrusting older rock over younger. There are two slopes to the mountain; the fault plane is the steeper of these. Many of the mountains of the Rockies have this type of structure (Fig. 77).

(2) **Folded mountains.**—The strata in this type are arched, forming a series of anticlines and synclines. The inclination of the strata in these folds may be gradual or steep, depending on the severity of the mountain-building movement. The pressure was exerted from the sides upon the stratified rock. The Jura mountains of the Franco-Swiss border and some mountains in the Rockies are examples of this type (Fig. 78).

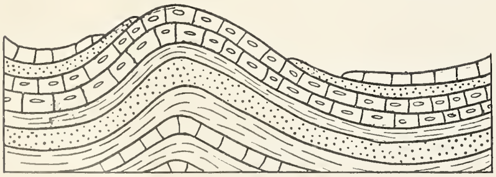

FIG. 78

Section of a mountain produced by folding; the crest of the anticline has been removed by erosion; the fold is asymmetrical, i.e., the limbs of the fold dip at different angles.

(3) **Normal mountains.**—As folding generally precedes faulting, it is to be expected that a combination of the two above-mentioned types will occur. It does occur so commonly that mountains having a folded and faulted structure are called normal. The larger mountain systems, Himalayas, Rockies (Fig. 79), and Andes, belong to this group. The strata may be steeply inclined, sharply folded, or faulted, and, upon denudation, will form rugged mountains as the resistant rocks are left in elevated positions. The structure of such mountains may be very complex; this is especially so of the Alps, for there has been much thrusting along fault planes, and folding has taken place at least twice.

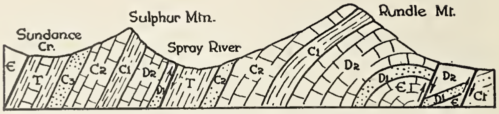

FIG. 79

Cross-section of the Rocky Mountains at Banff to illustrate normal mountain structure; both block and folded types are present; C Sawback formation (Upper Cambrian), D_1 Ghost River formation, D_2 Minnewanka formation, C_1 Banff shale, C_2 Rundle formation, C_3 Rocky Mountain quartzite, T Spray River formation, Ct Kootenay coal measures.

(After Warren, G. S. C.)

(4) **Batholithic mountains.**—These are composed of the batholithic cores from which much of the overlying sedimentary or other rock has been removed by denudation. The rock types are principally granites and related igneous rocks. The Coast Mountains of British Columbia are a good example of this type.

There are two other types of mountains of lesser importance; these are **relic** and **laccolithic** mountains. The relic type results from the erosion of a plateau in which a high elevation remains. The strata are about horizontal in this type. A relic mountain is comparable to a mesa, but there is no capping of rock. A laccolithic mountain (Fig. 31) gets its name from a **laccolith** (page 38). Henry Mountains in Utah, 11,000 feet high, originated in this way. The overlying strata have been removed by erosion, revealing the laccolithic core.

87. **Life History of Mountains.**—It was noted above that some of the highest mountains were once sea bottom. Let us trace their history from this beginning. Pressure from the sides, acting on the bottom of a basin, throws it into a series of gentle folds at first. As more pressure is applied, the folds become sharper and faulting takes place. At the same time the whole bottom of the basin is rising. Accompanying the faulting there may be volcanic activity, but earthquakes are a common occurrence. As soon as the land rises above the sea, it will be attacked by the agents of denudation, and will have therefore the two opposing forces, uplift and denuda-

tion, acting on it at the same time. As long as the uplift exceeds denudation, the mountains continue to get higher. The mountains are young, their youth being characterized by sharp ridges, peaks of resistant rock, glaciers on the peaks that reach above the snow-line, and deep valleys and mountain passes. The Himalayas and Alps are young mountains. The Rockies are in a stage of late youth.

When uplift ceases and denudation has full sway, then swiftly running water, frost (which is active in mountains the greater part of the year), changes of temperature, wind, rain, gravity, and glaciers lower the peaks and ridges, broaden the valleys, and remove the sharp angles of youth. As the peaks are worn down, first, below the snow-line the glaciers disappear; then, as they reach below the timber-line, the summits become forested as well as the slopes. The valleys may have enough soil and be level enough to be cultivated. The mountains are now mature. The Appalachians and the Highlands of Scotland are at this stage.

In old age the mountains have rounded contours and are quite low. Further erosion reduces the land to a peneplain with a few low scattered hills dotting it. The hills are the cores of the former mountains, and are probably of granite or some related rock. They are called **monadnocks.** Examples of old mountains are the hills of the Canadian Shield which encircle Hudson Bay and fringes on the Arctic Ocean, the Laurentide Hills along the north shore of St. Lawrence River, and the Brazilian Highlands. Stages in the erosion of mountains are shown in Fig. 80.

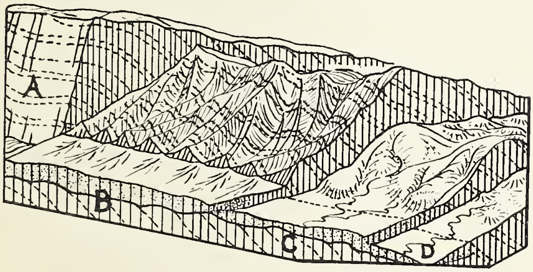

FIG. 80

Stages in the erosion of mountains; the original fault block A is eroded into the rugged topography of youth (B); C shows the same block when the sharp peaks and deep valleys give way to the rounded forms of maturity; D illustrates the final stage, a peneplain with a few scattered hills (monadnocks).

The peneplain may be uplifted, and once again erosion will carve ridges, which may be separated by broad valleys.

88. **History of the Rocky Mountains.** — In late Precambrian or early Cambrian time (see Geological Table for Alberta, p. 13), a downwarping of the earth's crust produced a geosyncline in what is now the eastern part of British Columbia and Western Alberta (Fig. 81). This was the Rocky Mountain geosyncline. It was invaded by the sea, and sediments, washed down from the high land to the west, began to accumulate in it. This deposition continued for millions of years, and thousands of feet of sand, clay, and limy materials were deposited during the Cambrian, Ordovician, Silurian, Devonian, and Carboniferous periods; but during Permian time the eastern part of the basin must have been above sea level, for there are no deposits of this age in the Rockies. Fluctuations in the width and depth of the geosyncline occurred, for alternating layers of quartzite, shale, and limestone are found in many places—evidence that each one of those particular places was close enough to shore at one time for sand to be deposited, but far enough at another time for limestone to form (Figs. 22, 23, 24). As these sediments were deposited, the sea bottom sank, so that the basin did not become filled with sediment and further deposition could take place. In Triassic and Jurassic periods the geosyncline was again occupied by a shallow sea; but in Cretaceous time the sea left the basin almost entirely, for most of the sediments de-

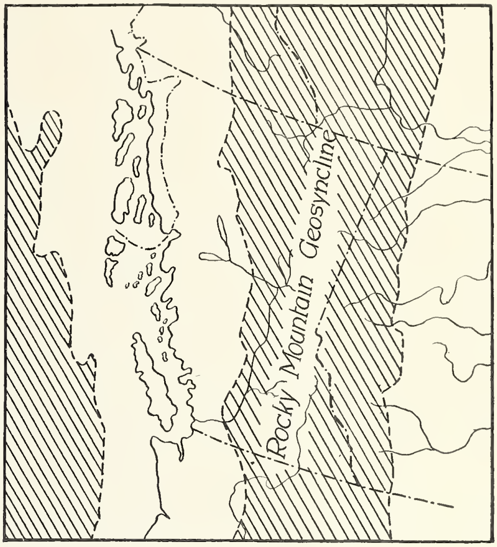

FIG. 81

Distribution of land (unlined) and sea (lined) in Alberta and British Columbia in the Cambrian period; sediments derived from the high lands to the east and west accumulated in the geosyncline to a depth of many thousands of feet, and now form the many different types of rock found in the Rocky Mountains.

posited then were laid down in fresh water. All told, over 50,000 feet of sediments were deposited in the trough. The geosyncline was in a disturbed condition, for its shorelines fluctuated because of continued uplift and subsidence. In early Tertiary time, probably Eocene, uplift accompanied by considerable pressure from the west took place, and the mountains were raised.

In this uplift so much folding and faulting took place that the strata now occupy a width of about one-half that of the basin in which they were originally deposited (Fig. 79). On the extreme east, Palaeozoic shales, quartzites, and limestones are as a general rule thrust over upon the younger Mesozoic (Cretaceous) strata. The arrows on each side of the fault plane indicate the direction of movement of the fault blocks (Fig. 79). The cross-section also shows normal mountain structure. Rundle Mountain belongs to the folded type, and Sulphur Mountain is a fault block dipping steeply to the west.

During and since the raising of the mountains, weathering and erosion have been very active, removing thousands of feet of sedimentary rock, and sculpturing the jagged peaks and sharp ridges which are now seen.

In Oligocene time there is evidence that a plateau, now known as the Cypress Plain, extended from the Rocky Mountains, which were then higher than they are now, across Alberta and into Saskatchewan. Across this plain flowed rivers and streams, and on it they deposited rock debris which they had acquired in the newly risen mountains. Nearly all of this plain or plateau has been removed by erosion, but some remnants of it are the Cypress Hills, which now rise several hundred feet above the land surface (p. 75). The Cypress Hills formation, which caps these hills, is about 125 feet thick, and consists chiefly of conglomerate and sandstone. The conglomerate is composed of pebbles and boulders of quartzite which came from the Rockies (Fig. 36).

Climatic changes at the end of Tertiary time brought about widespread glaciation in the northern half of North America. The climate had grown colder, and precipitation had increased. All of the snow had not melted during the summers and had accumulated to form glaciers. Mountains and plains alike show the effects of ice erosion. In some mountain valleys the ice was over 1,000 feet thick. The present site of Jasper was covered with ice to a depth of some 2,000 feet. Some mountain sides have the marks of glaciation upon them as high up as 8,500 feet above sea level, and ice completely covered some of the lower mountains such as Tunnel Mountain at Banff and Mount Coliseum at Nordegg. With the advent of a warmer climate the ice gradually melted from the plains and mountain valleys, and glaciers now are found only on the higher mountains.

Glaciers have been an important agent of erosion in the mountain areas by removing rock debris from the slopes, smoothing the floors of the valleys, and transporting the materials of erosion from one place and depositing them in another.

89. **Economic Importance of Mountains.** — Mountains are important to man as a source of minerals, lumber, and water power, as offering suitable sites for health resorts, and as impediments to transportation and communication.

(1) **Barriers to communication.** — As mountains generally occur in long chains they separate the land on either side. Here and there may be mountain passes through which communication may be effected. Sometimes it is necessary to construct tunnels to avoid climbing to great heights. The Alps are pierced in several places by tunnels; one of these, the Simplon tunnel in Switzerland is twelve and a half miles long, the longest in the world. There are several tunnels in the Canadian Rockies, by which the railways avoid steep grades. Lowering temperatures, glaciers, avalanches, storms, and the thinness of the atmosphere are further handicaps to communication over mountains.

(2) **Resorts.**—Mountains are popular resorts each year by reason of their lower summer temperatures, beautiful scenery, medicinal hot springs, swimming facilities, boating, mountain climbing, fishing, and hunting. Jasper and Banff have gained a world-wide reputation for the variety and excellence of recreations that they offer to the vacationer. The Alps have become one of the greatest resort regions in the world.

(3) **Water power.**—Owing to the increasing use of electrical power, mountain streams are becoming an important source of this commodity. Mining centres get their power from neighboring streams; and power may be sent even long distances to supply communities which are not so favorably situated in this respect.

(4) **Timber.**—As the slopes and sometimes even the summits are covered with timber, mountains furnish much of the lumber which is used today. Communities sometimes grow up where the lumber mills are located, but as soon as the supply of timber is depleted, the mills are moved to fresh reserves and the towns are deserted.

(5) **Minerals.**—Mountainous regions are the source of much of the metals and other products of the mine and quarry which are so much in

demand. Copper, zinc, lead, nickel, gold, silver coal, and building stones are some of the more important products.

Coal of the highest quality, anthracite, is found in strata which have been subjected to considerable folding. In Great Britain and eastern United States, the principal fields where this coal is mined are synclinal in structure, the anticlines having been removed by erosion. Some of the coal fields in the foothills of Alberta produce a lower grade of coal from somewhat similar synclines.

Most of the metal-producing mines are located in mountainous regions or in regions of worn down mountains. It has been noted above that batholiths form the roots of mountains and frequently supply the mineral matter of the deposits, which may be rich enough to be profitably mined. This mineral matter may be deposited in cracks and fissures in the bed rock or in cavities dissolved in it. Denudation operates rapidly in the mountains, and soon the overlying strata may be sufficiently removed to render the mineral deposit visible to the prospector. These mineral veins are exposed chiefly on steep slopes, because soil and vegetation cannot collect there to conceal them. The Purcell and Selkirk Mountains of Southern British Columbia produce much lead, silver, and zinc. The Sullivan mine at Kimberly is the largest producer of lead and zinc in the British Empire, the ore from which is smelted in Trail. In Ontario many of the large gold and copper mines are situated in regions which were once the sites of high mountains and the scenes of tremendous volcanic activity. The bodies of ore are associated with the intrusive rocks of batholiths, volcanoes, dikes, sills, etc.

The Rocky Mountains are very poor in deposits of metallic minerals, either because little mineral matter has been deposited in them, or because it is still buried in the interior of the mountains and will only be exposed by further erosion in future ages. There are several prospect holes near Field, but only one of these, the Monarch Mine, has been developed. This mine is located on Mt. Stephen near Field and has, off and on, produced zinc, lead, and silver.

* * *

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Questions:

1. (a) What is a mountain?
   (b) Give three characteristics of mountains as distinguished from hills, plateaus, mesas, etc.
   (c) When are mountains considered lofty?
   (d) Which continent is most mountainous?
2. (a) Distinguish between mountain, range, system and cordillera. Name one example of each in Canada.
   (b) Colour in the map on page 74 (Fig. 73) in the suggested colours.
   (c) What is the difference between an interior basin and a park?
   (d) Define peak and ridge. How were they formed?
   (e) Name the highest mountain in Canada, in the Canadian Rockies, in North America.
   (f) Account for the formation of water gaps and wind gaps.
3. (a) Give two ways in which mountain passes have been formed.
   (b) Which is the lowest pass in the Canadian Rockies? Where is it?
   (c) Where is the Great Divide? Why is it so called?
4. (a) The average temperature at the foot of a mountain is 45° F. What is the average temperature at its peak 6,000 feet higher?
   (b) Could a glacier form on the mountain peak in (a)? Explain.
   (c) What is meant by snow-line? Write a note on the position of the snow-line in various latitudes.

(d) Define timber-line. Is it higher on the north sides or south sides of mountains in the Rockies? Give reasons for your answer.

5. On a map of the world mark by heavy lines the principal systems of the two mountainous belts of the earth. Put in the systems named in section 84, page 77.

6. Outline briefly the theory that attributes the origin of mountains to radio-activity.

7. (a) State two features of block mountains. Draw a cross-section of a mountain of this type showing thrust faults.
   (b) Draw a diagram of a folded mountain.
   (c) What are normal mountains? Why are they thus named?
   (d) What are batholithic mountains? What rock type would you expect to find in these mountains?
   (e) What are relic mountains? laccolithic mountains?
   (f) Why are the Rockies classed as normal mountains?

8. (a) Give three important characteristics of young, mature and old mountains. In what stage are the Rockies?
   (b) What three agents would you select as having the greatest effect in the denudation of mountains? Give reasons for your answer.
   (c) Give four reasons for the conclusion that the Rockies are young mountains.

9. (a) Define geosyncline. Make a sketch to show the position of the Rocky Mountain Geosyncline during the Palaeozoic era. What estimated thickness of sediments was deposited in it?
   (b) What evidence is there that the shorelines of the epicontinental sea in (a) fluctuated greatly? Explain clearly.
   (c) How do geologists account for the absence of Permian rocks in the Canadian Rockies?
   (d) What explanation can you offer for the great width of the geosyncline as compared to the narrow width of the Rockies in the Canadian Cordilleras?
   (e) In what epoch were the mountains uplifted? Approximate the number of years ago.

10. (a) What was the Cypress Plain? How was it formed? What is left of it now?
   (b) Draw two profiles of the earth's surface from the Rocky Mountains to Cypress Hills, one as it was in Oligocene time, the other as it is now.
   (c) What two factors caused glaciation in the mountains?

11. (a) Enumerate six ways in which mountains are handicaps to communication.
   (b) List four ways in which the Rocky Mountains are of benefit to us.
   (c) Why are the best coal fields located in synclines? Give two reasons.
   (d) Give three reasons why mineral deposits are generally located in mountainous regions.
   (e) Why aren't big cities found in mountainous regions? Give four reasons.

Suggested Activities:

1. What was your conception of a mountain? Was this conception borne out in all cases?

2. If you have visited or intend to visit the Rocky Mountains, look for these features. Find examples of block and folded mountains. Do you enter the mountains by a water gap? What evidence is there that the channel of this stream was present before the mountains were raised, and that this gap was cut into the rock as the mountains were elevated? Note the presence of the timber-line. What evidences are there of youth in the mountains?

3. Use the apparatus suggested in Chapter I for producing folds and faults to make mountain types.

4. Is there any reason for believing that the Continental Divide, which forms part of the boundary between Alberta and British Columbia, is static or moving?

5. Make a clay model of a young mountain. Allow water from a tap to drip on it slowly, and note any changes in the outlines of the mountain as it passes from youth to old age.

CHAPTER IX

* * * *

GLACIERS AND GLACIAL EPOCH

90. **Origin of Mountain Valley Glaciers.** — If mountains are in a region of abundant precipitation and reach above the snow-line, all of the yearly snowfall will not melt, but will accumulate in valleys or in more or less horseshoe-shaped depressions called **cirques** near the mountain top (Fig. 83, a, b). As some peaks have as much as 150 feet of snow fall on them in one year (there would be no rain above the snow-line), great depths of snow collect in the cirques. The snow is compacted by its own weight into a mass of granular particles at the top and ice at the bottom, if there is great enough thickness. The granular snow is called **névé,** and the whole mass of it is an **ice-field** (Fig. 83a). One of the largest ice-fields south of Alaska is the Columbia ice-field situated at the headwaters of the Athabasca and North Saskatchewan Rivers. It covers an area of about 200 square miles and is the source of a number of glaciers such as Saskatchewan Glacier and Southeast Lyell Glacier (Fig. 82). But even though they are higher and colder than the Selkirks, the Rocky Mountains have fewer glaciers, for they are far from the sea beyond the regions of heavy precipitation.

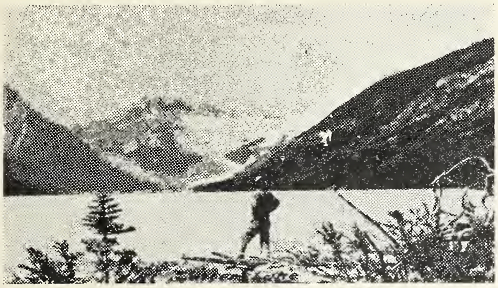
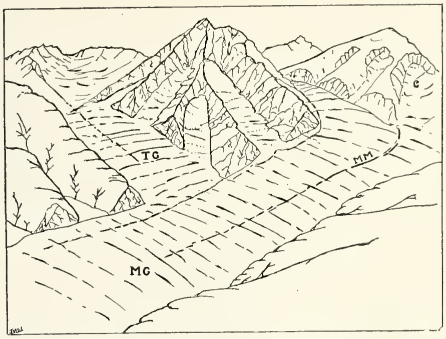


FIG. 82

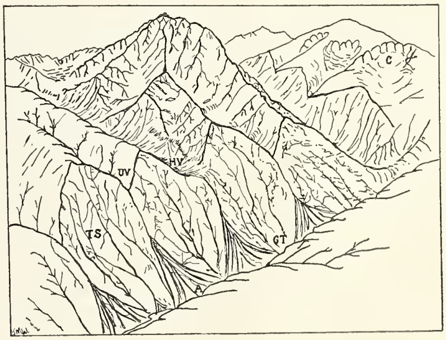
Glacier Lake in the Rocky Mountains; Columbia Ice-field and Southeast Lyell Glacier in the right background; note the U-shaped valley, typical of glacial action.

91. **Movement of Glacier Ice.**—As the ice-field develops on a slope, gravity and the weight of the accumulation above will cause the snow and ice to flow downwards just as water would, but much more slowly. (Experiments in the laboratory have shown that solids, even granite, will flow if the pressure is great enough). The ice flows to the snow-line, where it begins to melt; and the distance it will go below the snow-line before melting completely depends on the size of the glacier and the steepness of the slope. If the slope is great the glacier will move faster and get farther below the slow-line before melting; then too, if the glacier is a large one it will go farther before melting.

The melting of a glacier will not occur always at the same place, for this varies with the climate. If the climate gets colder the glacier will go farther down the valley before melting away, and is said to be **advancing;** but if the climate becomes warmer then the glacier will melt away farther up the slope, and is said to be **retreating.** The glaciers of the earth at the present time are in retreat.



(a)



(b)

FIG. 83

Ice sculpture in the mountains; in (a) is shown a glacier system with the upper surfaces of the glacier in accord (at the same level); (b) shows the mountain after melting of the ice; the floor of the main valley is below that of the tributary valleys which are left as hanging valleys; A alluvial fan or cone, C cirque, GT glacial trough (U-valley), HV hanging valley, MG main glacier, MM medial moraine, TG tributary glacier, TS truncated spur, UV unglaciated valley.

The rate of movement of glaciers has been measured in a number of instances by placing a row of pegs in a straight line across a glacier and noting at intervals the position of the pegs. Some Swiss glaciers move from one or two inches to four feet a day; Muir Glacier in Alaska moves about seven feet a day; and of some glaciers in Greenland the daily progress is as much as sixty feet. It was also evident that the movement was greater in the centre of the glacier, for the straight row of pegs formed an arc, convex downwards. By observing the movement of a similar row of pegs placed vertically in a deep crack in the ice, geologists have found that a glacier moves faster at the top than at the bottom. The ice is retarded by friction along the sides and bottom just as water in a river. These experiments with pegs show that the ice flows, and that parts of the glacier move at different rates.

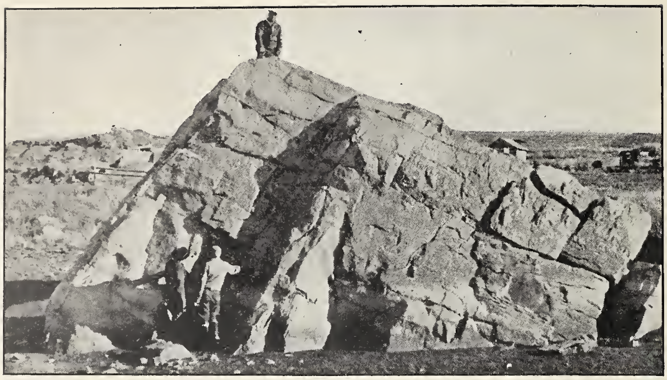


FIG. 85

A glacial erratic of quartzitic sandstone of Rocky mountain origin northeast of Glenwoodville in southern Alberta; tremendous pressure was needed to transport it.

92. **Erosion and Deposition.** — As a glacier moves over rough ground, it is broken into blocks. Pinnacles of ice or **seracs** separated by cracks or **crevasses** are then produced. Stones and other rock wastes are picked up and carried along by the ice. Such material is called a **moraine.** As the ice pushes against the sides of the valley, wearing them away, boulders, pebbles, and soil fall on it; this is a **lateral moraine.** If two glaciers meet, two lateral moraines combine to form a **medial moraine** (Fig. 83a). This moraine sometimes forms a ridge down the centre of the glacier, as it protects the ice below from the sun, while the ice on each side of it melts away. Large boulders on the glacier protect the ice below them in the same way, and in time become perched on a pillar of ice forming **glacier tables.** Friction of the moving ice on the floor of the valley tears loose large fragments of rock, and they are carried along; this is **glacial plucking.** These, along with fragments of the medial and lateral moraines which have fallen into crevasses and sunk to the bottom, make up the **ground moraine.**

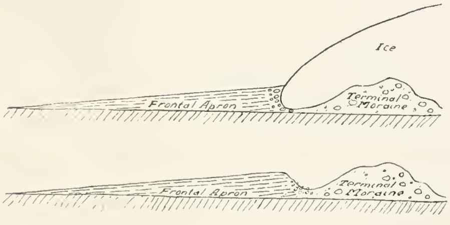


FIG. 84

Relative positions of frontal apron (or outwash plain) and terminal moraine before and after melting of the ice.

The ground moraine is an important agent of erosion, for it grinds the valley floor as it passes along, polishing, grooving, and scratching it. In this way the valley is deepened and widened.

During the melting of the glacier some of its load of unassorted boulders, gravel, and clay which made up the various moraines, etc., will be deposited; this is **glacial drift.** It may be deposited in a heap at the lower edge of the ice if the glacier neither advanced nor retreated for a long time, and is known as the **terminal moraine** (Figs. 84, 89). The terminal moraine is crescentic, for the glacier is tongue-shaped. Moraines may be built up to a height of 200 feet (Fig. 89). Advance of the glacier causes the terminal moraine to be over-ridden and spread out by the ice as the ice moves onward, The morainal material is compacted, consisting of a mixture of **rock flour** (powdered rock), sand, gravel, and boulders; this compact mass is called **till** or **boulder clay.** The pebbles and boulders are ground together and may show smooth surfaces and scratches, the latter being known as **striae.** Boulder clay is one of the most common indications of glaciation. Huge boulders measuring several feet across and weighing many tons may be carried great distances by the ice; these are called **glacial erratics** (Fig. 85). On the prairies of Western Canada there are many such boulders which have been brought down from the Canadian Shield. In the foothills of Alberta boulders of limestone and quartzite which were carried down from the Rockies are common (Fig. 85). Erratics have been found 8,000 feet above sea level at Banff—an indication of a depth of ice of several thousand feet at some former time.

When the glacier melts, the resulting water runs over the surface in streams, but soon drops into a crevasse of the glacier and continues its course as a subglacial stream along the bottom of the glacier in a tunnel through ice. A stream dropping into a crevasse may drill potholes or **giant kettles** two to twenty feet in diameter in the bed rock, for it strikes with great force on falling from such a height. They are drilled rapidly even in granite. The streams may carry with them boulders, pebbles, sand, clay, and rock flour. So much of the last may be carried in suspension that the water is white, in which case it is called **glacier milk.** The subglacial streams may deposit some of their load in the channels, but most of it is deposited at the mouths just beyond the terminal moraine. This assorted deposit is called an **outwash plain** or **frontal apron** (Fig. 84). The streams break up into smaller ones and flow across it. An outwash plain is generally smooth and has a gentle slope. In a narrow valley it is known as a **valley train.**

93. **Piedmont Glaciers.**—A valley glacier may flow down and spread out over a plain to form a **fan glacier,** and then unite with other fan glaciers to produce a **piedmont glacier** (mountain-foot glacier). It is really a variety of valley glacier. Malespina Glacier in Alaska is from sixty to seventy miles long and from twenty to twenty-five miles wide, and is formed from numbers of valley glaciers which originate in the St. Elias Mountains. The glacier has several medial moraines. Ross Shelf Ice of Ross Sea in Antarctica is a piedmont glacier, part of which is afloat (Fig. 86).

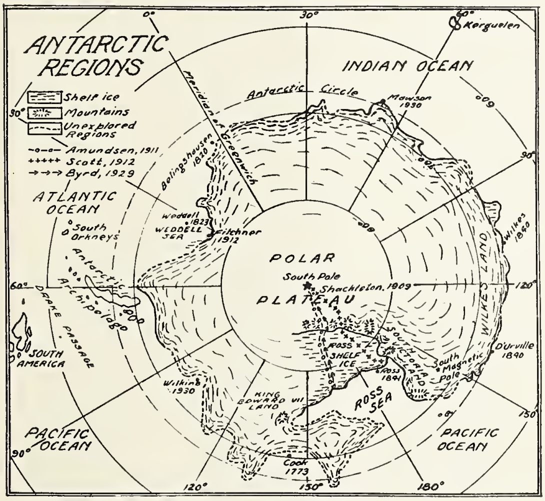


FIG. 86

Antarctica, a continent wholly covered by ice except for nunataks here and there.

94. **Continental Glaciers or Ice Sheets.** — These are typically developed in Antarctica (Fig. 86) and Greenland. They cover great areas, the Greenland Ice Sheet having an extent of about 500,000 square miles and the Antarctic Ice Sheet an area of about six times that. Ice sheets differ from valley glaciers in their greater extent, and also in the fact that they are not confined to valleys, for they may completely cover valleys, hills, and low mountains. The mountain peaks that project above the ice are called **nunataks.** The ice gets thicker towards the centre of the ice sheet, and at this higher elevation there may be snow. Both ice sheets mentioned above have at their centres elevations of about 10,000 feet above sea level.

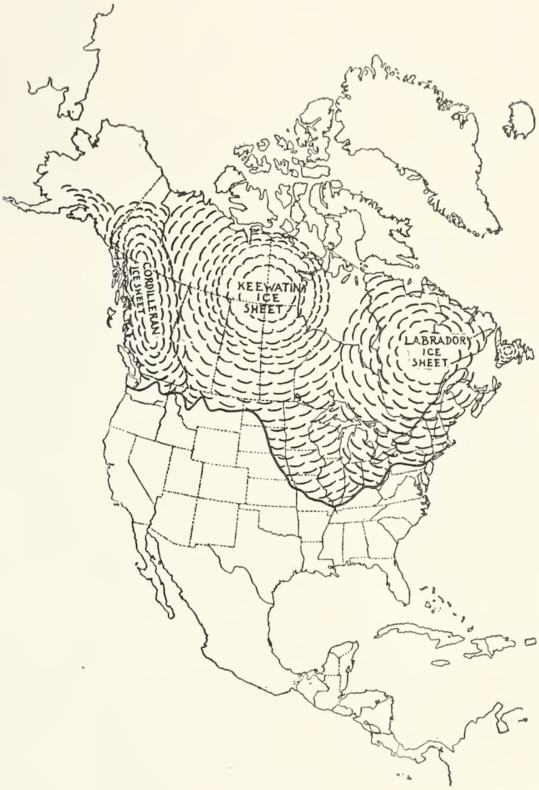


FIG. 87

Centres and extent of continental glaciers in North America in the Pleistocene epoch.

95. **Movement of Ice in Ice Sheets.** — Snow accumulates in the higher part of the continental glacier and is compacted into ice. The ice then flows out from the centre in all directions (Figs. 86, 87). Crevasses occur where the land surface is uneven enough to break the moving ice into blocks, and a slope of only two or three degrees is enough to produce them. Near the coast the ice sheet may be split up into valley

glaciers by mountain ranges. In some cases the valley glaciers reunite to form piedmont glaciers. The Ross Shelf Ice of Antarctica is a good example of an ice sheet of this type. Valley glaciers which sometimes flow down to the sea are called **tidal glaciers.** They erode the valleys, and on their retreat the sea enters the glaciated valleys, which are then known as **fiords.** Fiords are a common feature of the shorelines of the northwestern coast of North America, Norway and New Zealand.

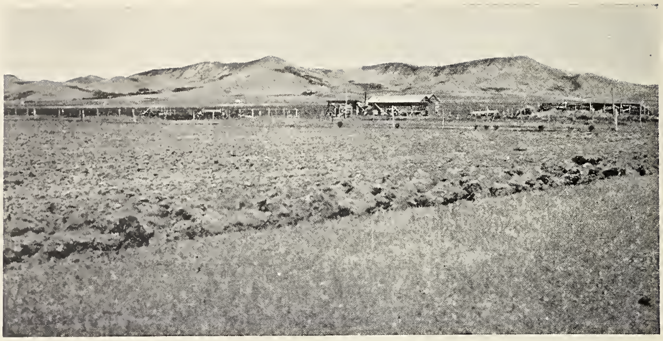


FIG. 89

A portion of the Neutral Hills, a terminal moraine near Viking; observe the irregular outlines, characteristic of moraines.

96. **Deposits.** — The surface of the continental glacier is free of rocks except where there are nunataks to supply rock debris. If there are valley glaciers on the outer margins of the ice sheet, they will develop moraines of various types. As lateral and medial moraines are generally lacking, the principal moraine transported by a continental glacier is the ground moraine, which it picks up by plucking and grinding. This load is carried from higher elevations to lower. Some of it may be dropped, covering the bed rock with a layer of till of varying thickness, in places several hundred feet thick.

Melting of the ice sheet on the surface produces streams, which soon find their way to the bottom and flow along ice tunnels to emerge at the front and deposit sand, gravel, etc., to build up an outwash plain. Terminal moraines, many miles in width and length, may be developed as the glacier advances and retreats (Figs. 55, 89).

97. **Source of Icebergs.**—Wherever valley or continental glaciers reach the sea, masses of ice are broken off, either through undercutting by the waves or by the upward thrust of the buoyancy of the water. These masses of ice or **icebergs** are of various sizes, being any bulk imaginable up to several miles in length, and rising as much as 500 feet above the sea. Only a fraction of the mass, from one-seventh to one-ninth, is above water, so that some of the larger icebergs must extend to a considerable depth below the surface (Fig. 88). They drift with ocean currents and are a menace to shipping. The loss of the "Titanic" on its maiden voyage was noted on page 34. Icebergs melt as they drift towards the equator, and the ground moraine which they contain becomes detached and is strewn along the ocean floor.

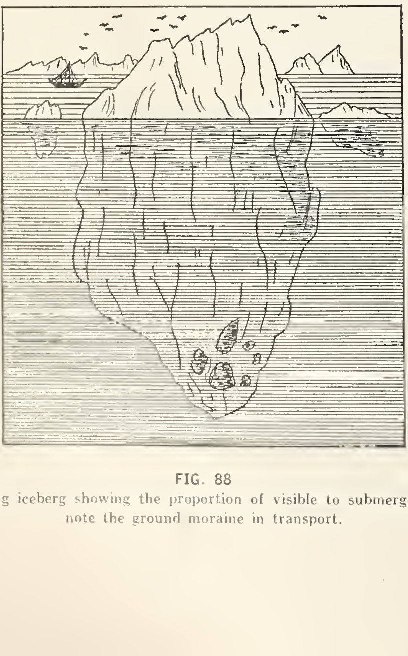


FIG. 88

Floating iceberg showing the proportion of visible to submerged ice; note the ground moraine in transport.

98. **Surface Forms Due to Glaciers:** (a) **Moraines.**—A few miles east of Viking, Alberta, there are a number of hills of irregular shape and of various sizes (Fig. 89). They are composed of unassorted rock flour, clay, sand, pebbles, and boulders, and are part of the terminal moraine of a continental glacier. The moraine extends from south of Medicine Hat northwestwards almost to the Athabaska River. There are several such morainal belts in western Canada, and also in eastern Canada and northern United States.

(b) **Kames.**—These are piles of more or less assorted sand, gravel, and small boulders, which were deposited under or in front of the ice-front of a glacier by sub-glacial streams. They are irregular in shape and vary in height. Some of them are very steep. Sometimes they are useful as a source of gravel for roads and of sand for building. Kames have been noticed at Sudbury, and at Winnipeg and other places in Western Canada. When the glacial geology of Alberta is intensely studied many more kames will undoubtedly be found, for they commonly occur with moraines.

(c) **Eskers.**—Sometimes a ridge of varying height is found winding across a plain. It is an **esker** and is composed of sand and gravel which were deposited in the bed of a stream. This stream flowed under a glacier which occupied that site at some remote time. The materials may have also accumulated in a gorge or crevasse in the ice. Eskers have been noted in Scandinavia, in New England, near the western end of Lake Erie, in Manitoba, and in the Northwest Territories, where they stand out prominently and resemble railway grades.

(d) **Drumlins.**—Low hills of boulder clay, in shape round or elongated but typically oval, and having smooth outlines, are sometimes found in regions that have been glaciated. They are from 100 feet to one mile in length and from twenty to 200 feet in height. It is thought that they were formed under the ice. They generally occur in clusters. They have been recognized at Port Hope, Ontario, near Winnipeg, and at Maligne Lake, southeast of Jasper.

(e) **Rounded and Fluted Hills.** — Whereas sharp outlines signify erosion by running water, gravity, frost, and changes of temperature, rounded forms are typical of erosion by glaciers. Glaciers grind off the sharp peaks and ridges, and remove the surface mantle exposing bed rock. The curved outlines of Tunnel and Stoney Squaw Mountains at Banff are due to valley glaciers which passed completely over them. Sometimes low rounded hummocks are carved out of bed rock; these are called **roches moutonnées** (sheep backs). They resemble drumlins in shape but are made up of bed rock not boulder clay (Fig. 90). A roche moutonnée is smoother and less steep on the side from which the glacier came.

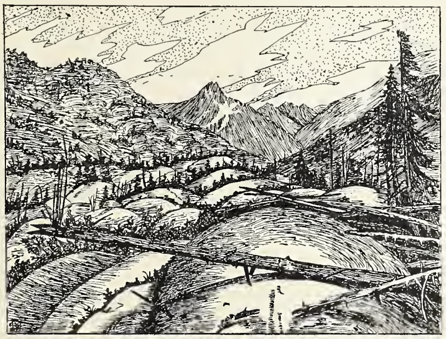
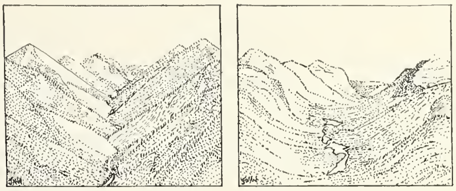


FIG. 90

Rounded surfaces of the bed rock (roches moutonnees) due to glacial erosion; Colorado.

Grooves or **fluting** are sometimes carved into the bed rock by rocks with which the base of a glacier is studded. The fluting is smooth and shallow, and is generally parallel to the longer axis of the elevation. Glacial striae are common in the bed rock of glaciated regions, and are useful for telling the direction in which the glacier was moving.

(f) **U-troughs.**—One of the most characteristic effects of glaciation in the mountains is the broad U-shape of the valleys. The grinding of the glacier on the bottom and sides removes the valley spurs of tributary valleys, and scours, polishes, and grooves the bed rock (Figs. 82, 83, 91). Many of the lower valleys of the Rockies show this form (Fig. 82). The floor of the valley may be rounded into roches moutonnées in places.



(a) (b)

FIG. 91

Ice erosion in a valley; (a) is a river valley with V-shape and spurs of hills projecting into it; in (b) is shown the same valley after glaciation now with U-shape and truncated spurs.

(g) **Hanging Valleys.**—Although a tributary glacier joins the main glacier with their upper surfaces at about the same level, the bottom of the main glacier will be below the level of the bottom of the other, for the main glacier is bigger and has eroded deeper. On the retreat of the glacier the floor of the tributary valley is left above the floor of the main valley, and is known as a **hanging valley.** If it is occupied by a stream the water cascades into the main valley and may build up an alluvial cone (Fig. 83b).

99. **Lake Basins.** — The formation of lake basins by means of glacial action was considered on page 48. The damming of mountain valleys by moraines forms lake basins (Fig. 55). Rivers may be dammed to form lakes, and many lakes now occur in the channels of rivers which carried off the water from the melting continental glaciers. During the continental glaciation, the weight of the ice depressed the land, and large lakes were formed in front of the ice sheet. Lake Agassiz (page 62), Lake Regina, and Lake Edmonton are examples of such glacial lakes. The beds of these lakes are now level plains. Many lakes of the tundra of northern Canada were formed by the scouring action of continental glaciers during the Pleis-

tocene epoch. Numerous rock basins in the mountains originated in a similar manner. To these might be added those lakes which occur in depressions between piles of glacial drift. There are many of these lakes in central Alberta in the moraines of the continental glaciers.

100. **Erratics.**—These were considered above. The source can generally be determined by the kind of rock. If it is of gneiss or granite or some allied rock, it most likely was carried down from the Canadian Shield by the Keewatin Ice Sheet; but if it is composed of limestone or quartzite, it was probably brought down from the mountains to the west by the Cordilleran Ice Sheet. Some erratics may have been carried by icebergs in a large glacial lake, and dropped as the ice melted.

101. **The Glacial Epoch:** (a) **Centres of Glaciation.**—In late Pliocene time or at the beginning of the Pleistocene, cooler temperature prevailed in the Northern Hemisphere. As more snow fell in winter than melted in summer, ice fields resulted. When the ice was several thousand feet thick it spread out. At the centres it was estimated to be 10,000 feet thick. In North America there were three centres of glaciation, viz., the Cordillera on the west, the west coast of Hudson Bay, and Labrador. These ice sheets are called the Cordilleran, Keewatin, and Labrador Ice Sheets respectively (Fig. 87).

The Cordilleran Ice Sheet occupied the valleys of the mountains, covering some of the lower mountains and leaving the higher peaks projecting above the ice as nunataks. Glacial erratics have been found as high as 8,000 feet in the Rocky Mountains; the ice, therefore, must have been several thousand feet thick in some valleys.

The Keewatin and Labrador Ice Sheets advanced and retreated several times, the limit of each advance being marked by a terminal moraine. In Western Canada there are several belts of terminal moraines which are more or less parallel and have a general northwest and southeast direction. These are located at Duffield, west of Edmonton; at Buffalo Lake, east of Lacombe; at Viking (Fig. 89); and along the Missouri Coteau. The morainal belts in places are as much as twenty miles wide. They probably mark the limits of four advances of the Keewatin Ice Sheet. In the east the ice sheets extended south of the Great Lakes, and there five different advances of continental glaciers have been recorded. Thousands of years elapsed between each advance of the glacier, for soil and peat are found between the different deposits of till and other glacial debris. The present epoch, the Recent, is considered by some as an interglacial period, i.e., a warm interval between two advances of the ice sheet, and in several thousand years a continental glacier will again advance from the north to cover northern North America and other parts of the northern hemisphere.

In Europe there were two centres of glaciation—one in the west which covered part of Russia, all of Finland and Scandinavia, and reached to the British Isles, and another which spread out from the Alps but did not meet the former.

(b) **Effects of Glaciation.**—The general effect of glaciation is to level the land by grinding off the higher elevations and by depositing glacial debris in depressions and valleys. Glacial drift is as thick as 500 feet in some places. At the same time glaciers give some relief to the land by the formation of moraines, out-wash plains, eskers, drumlins, erratics, and roches moutonées; but these have a low elevation and rounded outlines generally. In this connection might also be mentioned the formation of sand dunes and sand hills in Western Canada, for the sand is of glacial origin—probably from moraines, outwash plains, and the beaches of glacial lakes. The low elevation and rock basins of the tundra of Northern Canada were produced in part by glacial erosion.

The veneer of glacial drift which is spread over the northern half of this continent has developed in some places into a rich soil producing the finest wheat in the world. In some other places a barren soil of sand, gravel, and boulders has resulted. The dry beds of some glacial lakes have a fertile soil, which produces abundantly where the climate is favorable. The soil is composed of glacial drift which has been assorted by water. The dry bottoms of Lake Agassiz and other glacial lakes of the west are now extensively cultivated.

Drainage was greatly affected by the ice sheets. Many rivers have had their courses changed in places by deposits of drift in their channels. Bow River at Banff in pre-Glacial time flowed north of Tunnel Mountain, but its channel was blocked by glacial drift, and now its course is south between Tunnel and Rundle Mountains. In some places the channels were only blocked temporarily, and the rivers became lakes, in which sediment was deposited. On the removal of the dam the water again flowed in its channel, and the sedimentary deposits were left on the sides of the valleys as terraces. When the regular drainage channels were blocked by ice water from the melting ice, the stream carved new valleys, which became dry on the disappearance of the ice; these are not uncommon on the prairies. At those places where a river was forced to erode a new channel, the valley is in many cases young, but in other places it may be mature.

Many lakes were formed by the melting of ice and some of them were quite large. Lakes Bonneville and Agassiz have already been noted. The Great Lakes were at times larger than now, and were drained by way of Hudson and Mississippi Rivers, as ice blocked the normal drainage system. In addition to these large lakes many smaller ones formed in glacially eroded rock basins, in the depressions between piles of morainal material, and in other places; and for other reasons previously noted.

(c) **Cause of Glaciation.**—A number of theories which attempt to account for the widespread glaciation have been advanced, but each meets with serious objections, so that no single one is universally accepted. It has been suggested that if the poles were shifted so that the North Pole were about the centre of Greenland, the temperature would be low enough to allow glaciation. Another explanation supposes extensive emergence of the land areas, and temperatures in the interior regions low enough to permit the accumulation of snow. Elevations of the land areas would produce a like result. Some think that in the glacial age the earth did not receive as much heat from the sun as now, either because of a decrease in solar energy or because the sun's rays were partly obscured by the volcanic ash and dust of extensive volcanism.

Perhaps the most reasonable of all explanations is the lowering of temperatures by a decrease in the carbon dioxide content of the atmosphere. It is known that the carbon dioxide in the air acts as a heat blanket, and a decrease in the amount would bring about temperatures low enough to assist in the formation of glaciers. In the Pleistocene epoch decrease in carbon dioxide content may have been brought about through its great absorption by plants, which were very prolific in the time preceding glaciation. An increase in the carbon dioxide content would bring about a warmer climate in the Arctic and Antarctic regions. Further weight to this theory is given by definite proof of widespread glaciation in the Southern Hemisphere in the Permian period. This period was preceded by the Carboniferous, a time when there was much vegetation and great thicknesses of coal were formed in some parts of the world.

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Questions:

1. (a) What are the essential conditions for the formation of a glacier?
   (b) Why haven't the Rockies many glaciers?
   (c) What are the stages in the formation of a glacier?
   (d) Define: ice-field, cirque, névé.
   (e) Where is the Columbia Ice-field? How large is it? What rivers arise from it?
2. (a) What two factors cause movement of glacier ice?
   (b) What determines the distance that a glacier descends below the snowline? Explain.
   (c) What two factors will cause a glacier to retreat?
   (d) What two factors will cause a glacier to advance?
   (e) Does glacier ice flow or slide down a valley? Give reasons for your answer.
   (f) Define: sérac, crevasse, glacier table, glacial plucking.

3. (a) Name the four different kinds of moraines; give their position with respect to the glacier and the sources of materials.
   (b) Distinguish between glacial drift and boulder clay.
   (c) What is a fan glacier? a piedmont glacier?
   (d) Define: frontal apron, glacial striae, glacial erratics, glacial milk, giant kettle, rock flour, valley train.
   (e) Make a sketch to show the relation between a frontal apron and a terminal moraine.
4. (a) Give three distinguishing features of continental glaciers.
   (b) Briefly describe the movement of ice in a continental glacier.
   (c) What is the principal moraine carried by a continental glacier?
   (d) Define: nunatak, fiord, tidal glacier.
5. (a) What is the source of ice for icebergs?
   (b) Give two ways in which icebergs form?
   (c) What fraction of an iceberg is above water?
   (d) Why does this fraction vary? Give two reasons.
   (e) Of what importance are icebergs in transporting glacial debris? Explain.
   (f) Are icebergs composed of frozen fresh or salt water? Explain.
6. (a) Give the appearance, composition, and origin of each: drumlin, esker, kame, roche moutonnée.
   (b) Define: U-trough, glacial fluting, hanging valley.
   (c) Draw profiles to show the difference between an unglaciated valley and one that has been subjected to glacial action.
   (d) Make a list of six ways by which glaciers have formed lake basins.
7. (a) Sketch a map of North America, and mark on it the centres of glaciation in the Pleistocene epoch. How were these centres located?
   (b) How many advances of the Kewatin glacier were there in western Canada? in eastern Canada?
   (c) About how many years have elapsed since the last glaciation?
   (d) Give three important effects of the Pleistocene glaciation on Canada.
   (e) How many years it is since the beginning of the Pleistocene Epoch? How many years did it last? How many years since it finished?
8. Outline the carbon dioxide theory which accounts for the widespread Pleistocene glaciation.
9. All Alberta excepting the higher mountain peaks and ranges was glaciated during the Ice Age. Can you find three evidences of this glaciation near your home?
10. Is it probable that Western Canada will once more be glaciated? Explain.

Suggested Activities:

1. Support an icicle or thin sheet of ice at the ends and attach a weight to the middle. Keep at a temperature just below the freezing-point of water; notice how the ice bends under a small but constant pressure. This experiment demonstrates the plasticity of ice and its flowing under pressure in glaciers.

2. Take a handful of loose snow, and squeeze it in the hands to form a snowball. Why do the flakes cohere? It is because the pressure causes melting; and on the release of the pressure freezing again takes place (regelation) so that the flakes are cemented together by ice. Why does a temperature near freezing-point yield better snowballs? It is owing to the lowering of the melting-point of ice by the weight of the overlying snow that the snow underneath is compacted to form névé and ice.

3. Put a piece of ice in an overflow can with the water as close to 0° C. as can be obtained, and measure the overflow. This gives the volume of ice below water level. Now find the volume of the ice by pushing it below the surface with a slender wire, and catch the overflow. The volume of the ice is the sum of the two overflows. Calculate the fraction of ice above water. This experiment illustrates how much of an iceberg is actually showing. Would the same proportion of ice be above the surface if the water were salty? Perform the experiment outlined above using salt water of the salinity of the ocean.

4. Make a model of a valley glacier. Shape the mountains from stiff mud and use granulated salt for the ice and névé. Show the different moraines (by means of sand and small pebbles), U-valley, ice-field, cirque, glacier table.

5. Evidences of glaciation are abundant on the plains and in the foothills and mountains; therefore it will not be necessary to travel far from the classroom in order to find this evi-

dence. Look for glacial erratics. Are they composed of igneous, sedimentary, metamorphic rock? If they are sedimentary, then the probable source is the Rocky Mountains. Examine the soil and subsoil in a road or railway cut, or cut bank. Is it stratified or unassorted? If unassorted it is most likely boulder clay, and it should be searched for striated pebbles and boulders. If the bed rock is hard, find a fresh exposure of it in a road cut; look for glacial striae. Note the direction of the striae, for these indicate the direction that the ice was travelling, and point to the centres of glaciation. Many hills are moraines; these can be identified by the lack of assortment of the clay, sand, pebbles, and boulders of which they are composed. Are the pebbles in the soil of the same kind of rock as the bed rock? If not, where did they come from, and in what manner were they transported? Search for other effects of glaciation other than those mentioned above.

6. What lakes in your district owe their origin to glaciers? Make a list of these lakes, and explain how glacial action formed their basins.

7. You learned in Section 40 that a small stream has a small valley, and that a large stream has a large valley; however some large valleys on the prairies have small streams or even none at all. How do you account for the formation of these valleys? Is their origin associated with glaciation?

8. Are there sand dunes in your district? What is the origin of the sand? Has it come from the blowing of the soil, the beach of a glacial lake, or from a terminal moraine? This last is the source of the sand for many sand dunes in Alberta.

CHAPTER X

* * *

CLIMATE

102. **Weather and Climate.**—Care should be exercised in the use of these terms, for they have not the same meaning. **Weather** is the condition of the atmosphere at any time with respect to temperature, barometric pressure, direction and velocity of the wind, humidity of the air, and the state of the sky (i.e., clear, partly cloudy, cloudy, etc.) The weather at any place may vary from day to day or even from hour to hour.

Climate is the average weather condition of a region as observed over a number of years. It may change very slowly, but such changes are determined only over very long periods of time. Accurate records have detected no climatic changes anywhere in the last 150 years. But changes in the climate of the past are recorded in the rocks. Boulder clays and tillites are mute evidence that climates cold enough for continental glaciation occurred in Precambrian, Permian, and Pleistocene times; and parts of Canada, United States, Europe, South America, South Africa, and Australia have been covered with ice. Some of these same places have had warm enough and moist enough climates at other times for the luxuriant growth of mosses, cycads, ferns, etc., from which our most important coal beds have been formed. Even in the Antarctic regions the climate was favourable at some time long past for the formation of coal deposits.

There are several kinds of climate, some of which are: (1) dry, hot desert climate, typical of the Sahara and Arabian Deserts; (2) hot, rainy climate of the equatorial belt in some regions as in the Amazon Valley and interior Africa; (3) damp, equable ocean climate found along the coasts of some seas and oceans as in the British Isles and the northwestern coasts of North America; (4) extreme and variable or continental type of climate found in the interiors of continents (Alberta has this climate); (5) polar climate characterized by low temperatures and cold winds for the greater part of the year. Many factors involved in producing these various types of climate are discussed in the following sections:

103. **Factors Determining Climate.**—Latitude is the chief factor which determines climate, but its effect is modified or influenced by six other factors. These factors are: (1) altitude; (2) presence of large bodies of water; (3) presence of ocean currents; (4) location in the interior of a continent; (5) presence of prevailing winds; (6) presence of north-south mountain ranges.

104. **Latitude.**—The effect of the slanting rays of the sun on the temperature of the earth was noted on page 22. Differences in the size of the angle at which the rays strike the earth's surface divide the earth into five climatic zones (Fig. 92): (a) a tropical or torrid zone, exposed to the sun's rays more or less at right angles for a greater part of the year, and bounded on the

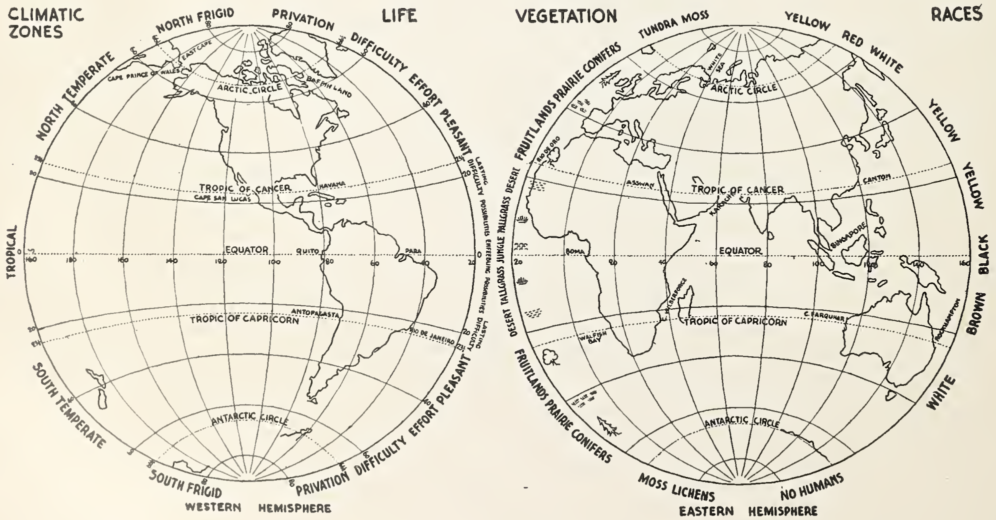

FIG. 92

The five climatic zones of the world, showing vegetation, races, and general climatic conditions.

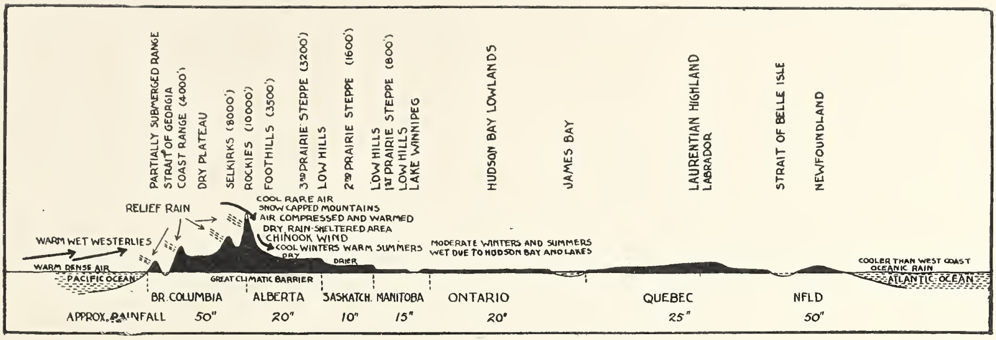

FIG. 93

A cross-section of Canada to show the relation of winds and topography in relation to the climate of the western provinces.

north by the Tropic of Cancer and on the south by the Tropic of Capricorn; (b) two temperate zones, where the rays strike at a lesser angle, extending from the tropics mentioned above to the Arctic and Antarctic circles respectively; (c) two frigid zones, receiving the rays at the smallest angle, and extending from the Arctic and Antarctic circles respectively to their respective poles. In Fig. 92 the boundaries between the zones are shown as smooth curves following the parallels of latitude, but actually they are quite irregular owing to the effects of the six modifiers, each of which is considered separately below.

105. **Modifiers of Climate: (1) Altitude.**—The effect of altitude on temperature was noted on page 23. The lowering of temperature with increase in elevation creates vertical climate zones. Thus, in equatorial regions where there are high mountains, the three climatic zones may be found—tropical at the base of a mountain, temperate above that, frigid at the peak. In Africa the high plateaus of the equatorial belt have a climate temperate enough for white people to live there in comfort.

(2) **Presence of large bodies of water.**—It takes more heat to raise the temperature of water than to raise that of other common substances. Therefore water will be comparatively cool, while neighbouring objects are warm or hot. Conversely, water gives up its heat slowly and may have a higher temperature than surrounding objects which lose heat readily. Hence islands, and regions bordering on seas, oceans, and large lakes have a more equable climate than other places, being cooler in summer and warmer in winter. Bermuda has warmer winters and cooler summers than places on the mainland in the same latitude; and the Great Lakes tend to prevent extremes of temperature in both summer and winter throughout the surrounding regions.

(3) **Presence of ocean currents.**—The drift of various ocean currents causes changes in temperature, and hence in climate; for winds blowing over these currents have their temperatures affected accordingly. The effects of the Gulf Stream on the climate of the British Isles, and of the Labrador Current on the north-eastern coast of North America have already been described on page 24. In this way ocean currents help to distribute the heat of the tropics in the cooler zones, and also to carry the cold water of the polar regions into warmer latitudes. This circulation of water helps to prevent extremes of climate along the continental margins. It is to be noted that isotherms are carried away from the equator by currents, such as the Gulf Stream and North Pacific Drift, which move away from it, and that they are carried towards the equator by currents, such as the Labrador Current, Bering Current, and Greenland Current, which originate in the frigid zones and are carried towards the equator bringing lower temperatures (Figs. 94, 95).

(4) **Climate in the interior of a continent.**—Unlike water, land heats up quickly and gives up its heat equally as quickly; therefore it is to be expected that regions far from the equalizing effects of bodies of water will be subject to greater extremes of temperature. In the long days and short nights of summer the land becomes warmed, but in the short days and long nights of winter the heat is soon lost by radiation. Accordingly there is great variation in winter and summer temperatures. On the prairies of Western Canada temperatures commonly vary from over 100° F. in summer to 40° F. below in winter—a range of over 140° F. As a rule these regions of extreme temperature are dry, winds from the sea having lost moisture before reaching them. Fig. 13 illustrates this fact. The interior regions of North America are about the driest parts of the continent.

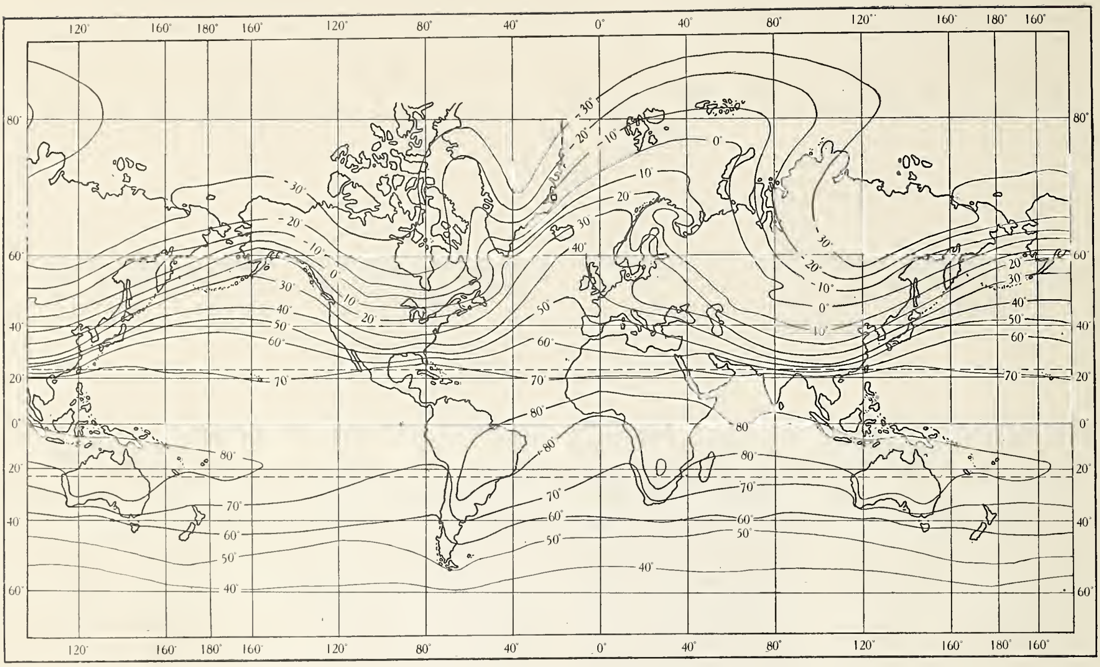

FIG. 94
Isotherms of the world showing average temperatures in January.

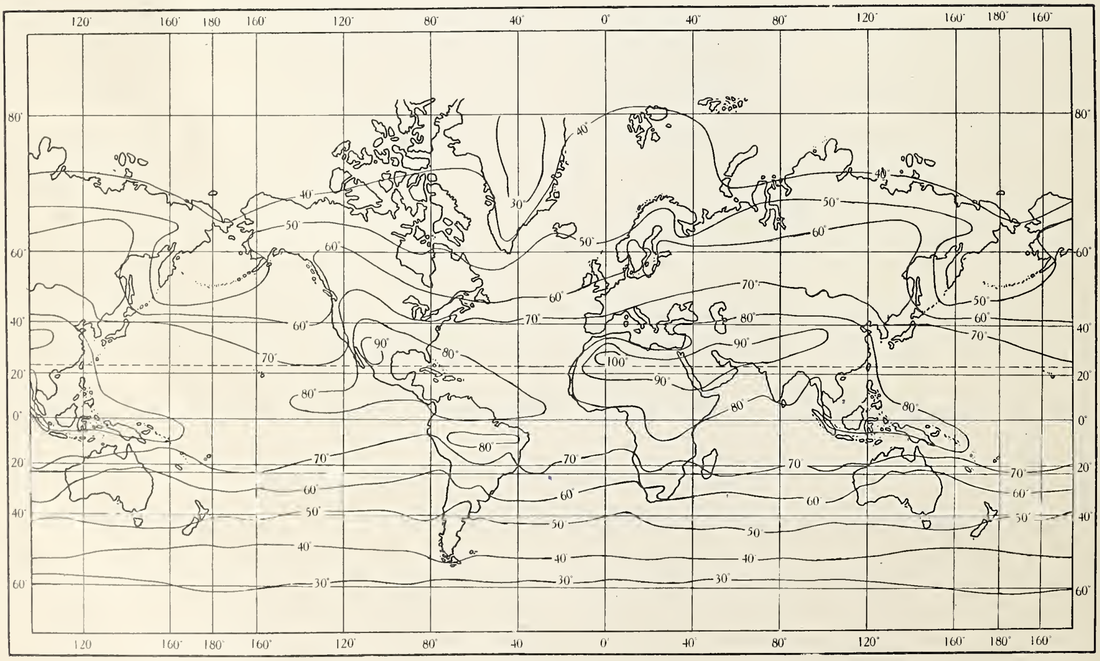

FIG. 95
Isotherms of the world showing average temperatures in July.

Contrary to common belief, the region of greatest cold in the northern hemisphere is not the North Pole, but it centres about Yakutsk in Siberia in latitude 63 (Fig. 94). The North Pole is a water area and subject to its equalizing effect. The coldest recorded atmospheric temperature, 80° F. below zero, was registered on the Antarctic Plateau.

Notice in Fig. 94 how, as a rule, the isotherms in winter bend towards the equator on the continents, and away from it on water areas; in summer the reverse is true (Fig. 95).

(5) **Presence of prevailing winds.** — The effect of winds on climate is very important, for they transport heat and moisture. Without them, ocean currents, large bodies of water, and large tracts of land would have no effect on climate. The winds of the earth occur in belts because of unequal heating of the earth's surface (page 20 and Fig. 17). Between some wind belts regions of calms occur. These belts of winds and calms lie approximately between the following parallels of latitudes: (a) **doldrums** (calms) from 0° to 10° on each side of the equator; (b) **northwest trade winds** from 10° to 25° north, and **southeast trade winds** from 10° to 25° south; (c) **horse latitudes** from 25° to 40° north and south of the equator; (d) **prevailing westerlies, cyclonic winds,** or **anti-trade winds** from 40° to 50° north and south of the equator; (e) **polar winds** from 50° to 90° north and south of the equator. The wind belts migrate north with the heat equator in our summer and south with it in winter.

(a) The **doldrums** or **equatorial calms** are caused by the rising of the warm air above the heat equator, which is the belt of greatest heat. They are low pressure calms, for the air is warm and expanding. The climate of this belt is monotonous, being characterized by heavy rains almost daily and few changes in weather.

(b) **The trade winds** blow towards the equator with great regularity. As they blow from the northeast and southeast, land areas in their paths will have heavy precipitation on the east coasts and perhaps deserts in their interiors. The Sahara is the best known of these trade wind deserts, but others occur in all the continents. The pounding of the waves on eastern sides of islands in this belt has cut cliffs, but on the western and leeward sides there are generally quiet harbours. The west coasts of continents in this belt are generally dry. California, which lies in the path of trade winds, is quite dry.

The doldrums and trade wind belt together make up the **tropical zone.** In this zone are situated the monsoon regions of the world. In winter the winds blow from land to sea, and consequently the climate is cool and dry, but in summer the winds are from the sea, bringing heavy rains to the land. The principal monsoon regions of the world are in southern China, Burma, southern and northeast India (better developed here than any other place in the world), Abyssinia, Central America, West Indies, and the northern tips of Australia.

(c) The **horse latitudes** are a belt of high pressure calms caused by the descent of the air which has risen above the doldrums. This belt constitutes the **sub-tropical zone.** Light variable winds may occur.

(d) The belts of **prevailing westerlies** take in most of the temperate zones of both northern and southern hemispheres. The winds blow towards the poles but are deflected to the east moving in a direction opposite to that of the trade winds, hence the appellation **anti-trade winds.** They are stronger on hot days, and are steadier on sea than on land, for the latter offers obstructions to their passage; accordingly they are better developed in the southern hemisphere which has a greater water area than the northern hemisphere. In the southern hemisphere they occur in the "forty" latitudes; hence these regions are termed by sailors the **Roaring Forties.** The climatic effect of the westerlies is the opposite of that of the trade winds; that is, west coasts have heavy precipitation while east coasts have light. Refer to Fig. 13 and note the heavy precipitation on the west coast of Canada and Alaska and the scanty precipitation of northern Canada. The west coast of Europe also illustrates this effect.

The prevailing westerlies do not blow steadily from the one direction but at times are broken up into vast whirls of air, comparable to eddies in water. In North America these spiral whirls, up to 1,500 miles in diameter, move across the continent at its widest part from west to east at the rate of 600 to 700 miles per day. There are two kinds of whirls, **cyclones** and **anticyclones** (which are not to be confused with such destructive winds as tornadoes).

In cyclones the centre of the whirl is an area of low pressure or "low" towards which the air moves but is deflected by the rotation of the earth, so that its direction is counter-clockwise in the northern hemisphere and clockwise in the southern hemisphere. In anticyclones the air moves outwards from an area of high pressure or "high" in a clockwise direction in the northern hemisphere and counter-clockwise in the southern hemisphere. Highs and lows are plotted on weather maps (Fig. 96) by means of **isobars,** which are lines joining points having the same barometric pressure (which is recorded in tenths of inches). Isobars form more or less

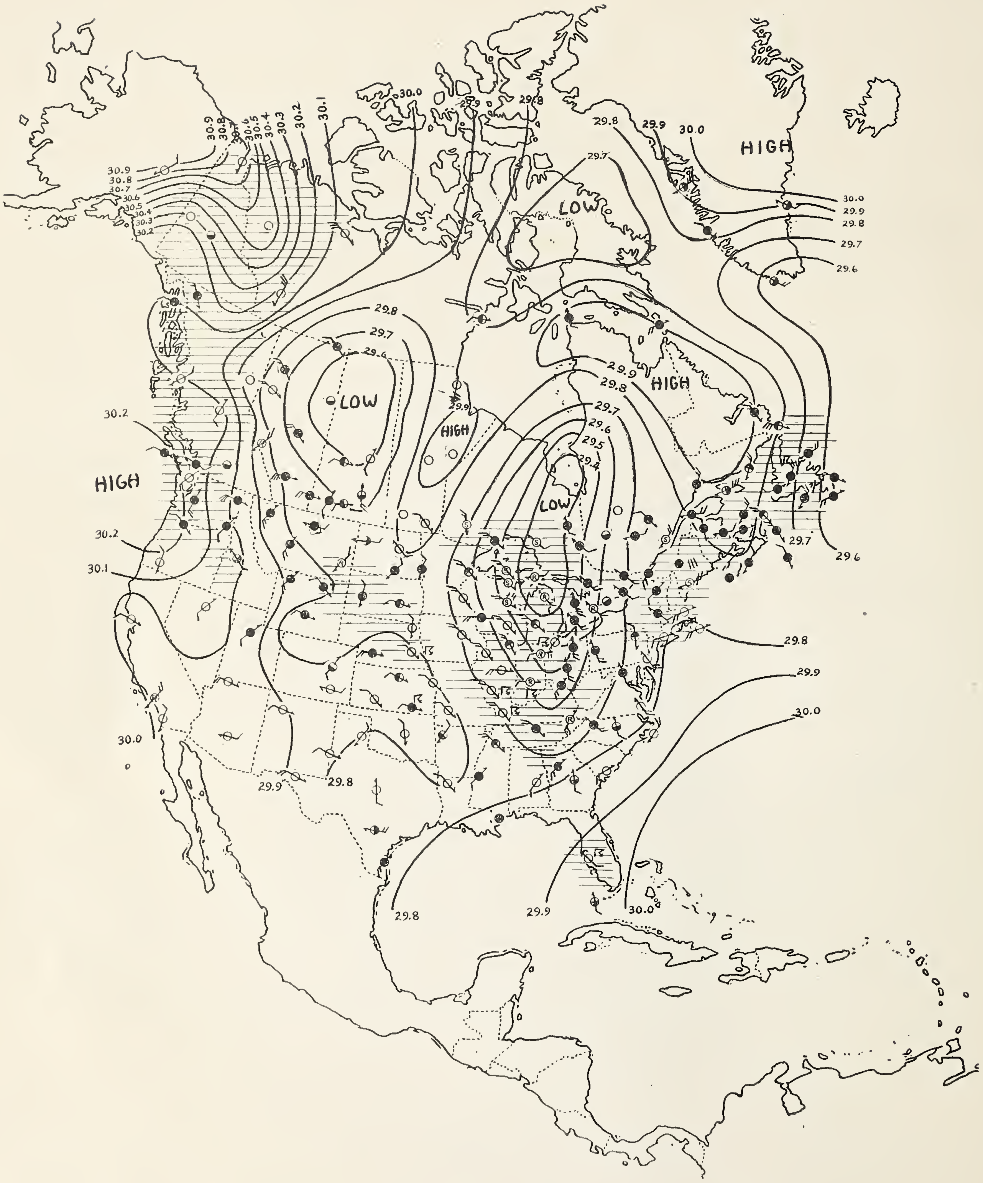

FIG. 96

Weather map of Canada for April 1, 1939; the procession of highs and lows is moving from west to east; arrows indicate the direction of the wind and the number of tails on them is proportional to its strength; circles are shaded into to the extent that the sky is overcast at that locality; horizontal lines cover areas of precipitation within the last 24 hours.

concentric circles or ovals. As cyclones and anticyclones move across the continent, any place in their path experiences changes in weather. When the place is on the east side of a low the winds are southerly or easterly, and the temperature is, therefore, higher; but when the low has passed, so that the place is on the west side of it, the winds are westerly to northwesterly, bringing cooler temperatures. Lows are characterized by relatively high temperatures, rain or snow, and shifting winds; highs bring lower temperatures and clear skies. From the information gathered by weather stations a weather map is made and weather forecasts are issued. The forecasts for Alberta and Saskatchewan on Saturday, April 1, 1939 (Fig. 96) was, "Northwest winds and somewhat colder tonight and Sunday with light snowfalls and flurries."

(e) The **polar winds** have not been studied very much, so that little is known about them. They originate in the frigid zone, which is characterized by long periods of extreme cold, so that the ground is snow-covered all or most of the year. There are only two seasons: winter, in which the sun does not appear above the horizon, and summer, in which the sun never sets.

(6) **Presence of north-south mountain ranges.**—As all prevailing winds blow in easterly or westerly directions, mountain ranges lying in the paths of these winds will have considerable effect on the climate of those regions. The winds rising to pass over mountains will have their temperatures lowered, and moisture will condense and fall as rain or snow. Therefore the windward sides of mountains in the path of winds blowing off bodies of water have heavy rainfall. The winds descend as drying winds on the leeward sides and may cause desert or semi-desert conditions there. The mountains of the west coast of Canada give ample precipitation to that region but create semi-desert conditions in southern Alberta and southwestern Saskatchewan.

Mountain ranges also modify the climate in another way. The Alps of Europe tend to shut out the cold north winds from the regions to the south of them, and to keep in the warm winds from the Mediterranean Sea. Thus extremes of climate in the Mediterranean areas are practically unknown.

106. **Climate of Canada.**—On account of its size (3,694,863 square miles) and its geographical position (extending from the Atlantic Ocean to the Pacific and from 40° N. latitude to 83° N.), Canada has a variety of climates; for these circumstances along with its physical features allow all the modifying factors of climate to exert their influence in various parts of the country. Southern Canada is in the temperate zone, but a large part of the Dominion lies in the frigid zone.

The principal factors governing the climate of Canada are latitude and prevailing winds. The latter move across Canada from west to east in a succession of cyclones and anticyclones (Fig. 96), bringing rapid changes in weather. The Canadian cordillera has considerable effect on the climate of the prairie regions, for the cyclonic winds lose moisture on passing over it, and reach the interior as drying winds. The west coast is thus a region of heavy precipitation, while the prairie provinces have a comparatively light rainfall. The precipitation of the prairies is derived principally from the moisture brought north by winds from the Gulf of Mexico. From time to time masses of cold air from the north pass freely over Canada, there being no mountains to obstruct their passage. These winds bring lower temperatures.

The west coast of Canada, being in the path of the North Pacific West Wind Drift, has an equable ocean climate having mild winters and long cool summers. The rainfall is fairly heavy, being about 100 inches a year on the west coast of Vancouver Island. In 1931, at one place on the Island, Henderson Lake, the precipitation was 319 inches, a record for the whole North American continent. Along the coast of the mainland the climate is warm and damp, but towards the interior it becomes drier and colder as the distance from the ocean and the altitude increase. In the Interior System of Plateaus (Fig. 73) the climate is so dry that in the Okanagan Valley fruit can be grown only on irrigated land. The valleys between the mountain ranges have a north-south trend, allowing cold winds of the north easy access and resulting in waves of lower temperatures, in winter especially. Mountain peaks reaching above the snow-line may be considered to be in the frigid zone.

The plains region east of the Rocky Mountains has a continental type of climate. In summer, when the days are long and the nights are short, the temperature becomes quite high, and particularly so if there is no wind for several days. Summer isotherms in this region move away from the equator (Fig. 95). In winter, because nights are long and days are short, much heat is lost by radiation, and lower temperatures result as the land becomes colder and colder. Winter isotherms dip towards the equator (Fig. 94). The air in winter, however, is dry and invigorating, and the cold is not felt as much as it would be in a humid climate. The low winter temperatures may be still further depressed from time to time by masses of cold air from the north. Blizzards often follow the first appearance of one of these cold waves. In summer a temperature of 110° F. and in winter one of 40° F. below zero are not uncommon, thus giving a range of 150° F. between summer and winter, and indicating an extreme type of climate—a characteristic of the continental type. The precipitation of the greater part of the prairie provinces is about fifteen inches a year, of which from sixty to seventy-five per cent falls during the growing season and can be used by plants. The amount varies from year to year, and crop failures because of drought are not unknown in several parts. As was mentioned above that the precipitation is derived chiefly from the moisture-laden winds from the Gulf of Mexico, and so the crops depend on the inflow of these winds for their moisture.

Alberta has one of the most variable winter climates in the world. In addition to the prevailing westerlies, which bring frequent changes in weather, and the cold waves from the north, **chinook winds** are of frequent occurrence. They are winds which have crossed the mountains rapidly, have become compressed (and hence warmer) on descending, and have reached the prairie as warm, drying winds. They come quickly and may effect a rise in temperature of 60° F. in only a few hours. The chinook winds blow from the southwest and west, and though they are felt chiefly in the southern part of the province, their effect may extend as far as Peace River and central Saskatchewan. Saskatchewan and Manitoba have winters similar to those of Alberta but with more continuous cold.

How great a moderating effect the Great Lakes have on the climate of Ontario is not definitely known, but nevertheless regions close to them do not experience the extremes of temperature found to the east and west of them. In southern Ontario summers are warm and sunny with showers of rain. The annual precipitation of about thirty inches is evenly distributed throughout the months of the year. North and northwest of the Great Lakes greater extremes of temperature occur, as these regions are beyond their tempering influence and are exposed to the cold north winds. Along the St. Lawrence valley the climate is very much like that of Southern Ontario, but increases in severity as one proceeds farther from the moderating effect of the Lakes. Summers are warmer, winters are colder, and frosts are more frequent.

In the Maritime Provinces a continental type of climate prevails, as they are in the path of the westerly cyclonic winds. Along the coasts the ocean tempers the climate; hence there are no rapid changes in season. But in the interior, as towards the centre of New Brunswick, the climate is severe. Precipitation is from thirty-five to forty-five inches a year and heavy snows in winter result. As Prince Edward Island lies in the Gulf of St. Lawrence it escapes the Atlantic storms.

In northern Canada lower temperatures than in other parts of Canada prevail. There is not much data regarding the annual precipitation in the north, for owing to the high winds it is difficult to distinguish between drifting and falling snow. Precipitation is considered scanty, for in winter snow is not very deep on the level, and often bare ground is exposed. Note that the winter isotherms (Fig. 94) dip southwards in this region, especially between the 75th and 105th Meridians, where there is the belt of greatest cold. Here in a region beyond any influence of warm Pacific winds the temperature is dominated by cold north winds. It is of interest to observe the influences of bodies of land and water on the temperature of the polar regions. The delta of the Mackenzie River within the Arctic Circle, supports a fairly strong growth of trees, shrubs, etc., but within the Antarctic Circle the only plants are mosses, algae, and other low forms of plant life which cling to the rocks of nunataks. In the one case the waters of the Arctic Sea and the presence of a land mass to the south of it help to raise the temperature, but in the latter case extremely low temperatures prevail on the Antarctic Plateau in winter, so that even in summer there is not sufficient heat to melt the snow, for the winds blowing north off the ice cap remain cold.

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Questions:

1. (a) Distinguish between weather and climate.
   (b) Is there any evidence of changes of climate in the past? Explain.
   (c) Describe the five different kinds of climate. Where can each be found?

2. (a) Draw a diagram to show the five climatic zones as determined by latitude.
   (b) What six factors make the curved boundary lines of those zones irregular?

3. (a) What is the general effect of altitude on temperature?
   (b) Explain how the presence of large bodies of water affects the temperature of adjacent land areas.
   (c) Name two ocean currents that raise the temperature of a place, and two more that lower the temperature of another place. How do these currents affect isotherms?
   (d) Why do interiors of continents have hot summers and cold winters generally? Explain fully.
   (e) Where is the coldest place in the northern hemisphere?
   (f) How do large land masses affect isotherms?

4. (a) Account for the formation of winds.
   (b) Name the different belts of winds and calms, and give their approximate positions.
   (c) Why do these belts move north and south?
   (d) What weather is typical of the doldrums? of the trade wind belts? of the horse latitudes?
   (e) How do monsoons originate? Where are they typically developed?

5. (a) Why are prevailing westerlies stronger on sea than on land?
   (b) How do prevailing westerlies affect precipitation?
   (c) Give three differences between cyclones and anticyclones.
   (d) What is the difference between a cyclone and a tornado?
   (e) Define: isotherm, isobar.
   (f) A town in Alberta is on the east side of a high. From what direction is the wind coming?
   (g) What kind of weather does a high bring?
   (h) What kind of weather does a low bring?

6. (a) What is the chief characteristic of weather in the polar regions?
   (b) What seasons are found in the polar regions?

7. (a) How does the presence of a north-south mountain range affect climate in the trade wind belts?
   (b) How does it affect climate in the belts of prevailing westerlies?

8. (a) What are the principal factors that affect the climate of Canada?
   (b) Write a note on the climate of the west coast of British Columbia.
   (c) Why have the Canadian prairies a continental type of climate? Explain fully.
   (d) Where is the source of most of the moisture that falls in western Canada?
   (e) What three factors make the climate of Alberta so variable?

9. (a) Write a note on the climate of southern Ontario.
   (b) Describe briefly the climate of the St. Lawrence valley.
   (c) Why have the Atlantic provinces a continental type of climate? What factors modify the climate?
   (d) In your opinion which region in Canada has the most favourable type of climate generally? Give reasons.

10. On a map of the world sketch roughly the mean isotherms of the world for July (in red) and for January (in blue).

Suggested Activities:

1. From day to day keep a record of the temperature, barometric pressure, wind direction and velocity, state of the sky, and humidity. These readings should be made at the same time each day, and immediately recorded on a chart. Note any relationships between the factors stated above and the kind of weather they bring. Then an attempt can be made to forecast the weather from the information gathered. Obtain from the Department of Transport, Meteorological Division, Toronto, copies of weather maps for the period of your observations, and compare your records with the official records and forecasts.

2. Study the symbols on a weather map until you know their meaning. Check the reported weather with your record of the same area.

3. Find the isotherm nearest to your home in figures 94 and 95, and follow this isotherm across the map. Can you account for each change in the direction of this isotherm? Apply the principles learned in Section 105.

4. Study the weather maps of successive days to note the procession of highs and lows across North America.

CHAPTER XI

* * *

ECONOMIC GEOLOGY OF ALBERTA

Introduction

107. **Definition.** — Economic geology is the study of deposits of minerals that may be of use to man. All such deposits are not developed, for development depends on a number of factors such as size of the deposits, market value of the product (a variable quantity), demand for the product, cost of mining, cost of extracting the product from the ore, and cost of transportation to markets. Increased value of the product, improved methods of mining and extraction, cheaper transportation, new uses, etc., may lead to the working of deposits which formerly could not be profitably worked. For example, the increase in the price of gold in 1933 from $20.67 an ounce to about $35.00 led to the development of many gold mines which could not be operated profitably at the lower price.

108. **Diamond Drilling.**—After a mineral deposit has been discovered, the lateral extent and the depth are generally determined by sinking a number of holes by diamond or core-drilling. Samples of the minerals are also obtained, as well as structural details, which will be of use if the deposit warrants development.

The diamond or core-drill outfit consists of hollow rods screwed together. The rods are from one to several inches in diameter and five or ten feet in length. The whole line of them is rotated by an engine. At the lower end of the line (or drill stem), there is a circular ring, the bit, which is studded with black diamonds or carbon. The bit cuts a circular hole and leaves a cylinder of rock, the "core", in the centre. Water is circulated in the hole to keep the bit cool and to wash away cuttings of rock. At intervals of from five to thirty feet the stem is withdrawn and the core with it, a special device being used for the latter purpose. The core is removed from the stem for examination, the rods are lowered, and the process is repeated until the desired depth or the key bed is reached. This method is inexpensive and rapid. It is used to work out the geological structures of oil fields as well as to investigate mineral deposits.

109. **Mineral Wealth of Alberta.** — The annual mineral production of Alberta is about $25,000,000. Over 95% of this amount is accounted for by fuels; viz., coal, petroleum, and natural gas. Alberta is rich in these deposits as well as in deposits of non-metallic minerals, but no valuable ore deposits of metallics have yet been discovered in the province. The prospective areas in which metallic minerals might be found are practically limited to the small area of the Canadian Shield around Lake Athabaska. In the following discussion of the mineral deposits of Alberta, these divisions will be used: coal, petroleum and natural gas, metallic ore deposits, non-metallic ore deposits. The locations of the deposits are shown in Fig 97.

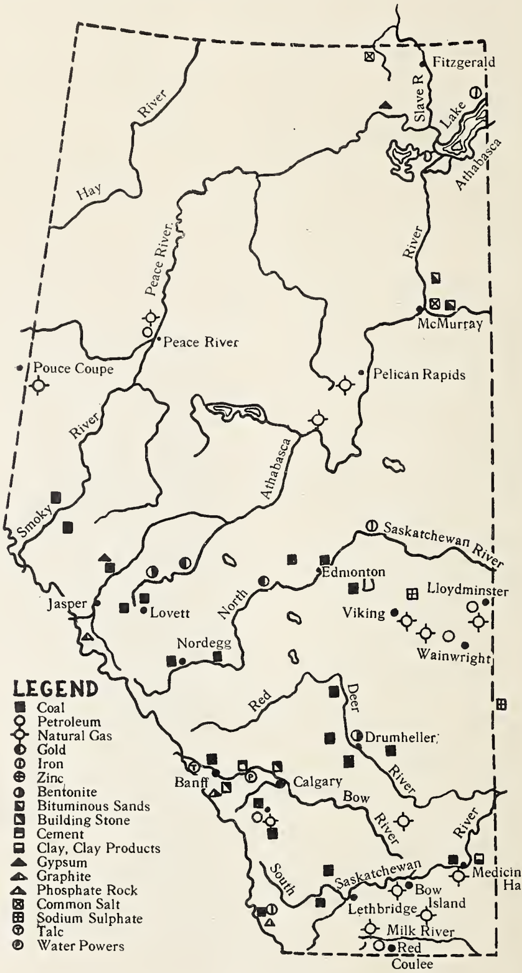

FIG. 97

Map showing the important mineral deposits of Alberta.

The following reports give much information regarding the descriptions, occurrences, uses, price, production, etc., of minerals found in Alberta and Canada:

First Annual Report on the Mineral Resources of Alberta by Dr. J. A. Allan, University of Alberta, Edmonton (1920).

Second Annual Report on the Mineral Resources of Alberta by Dr. J. A. Allan, University of Alberta, Edmonton (1921).

Annual Report of the Department of Lands and Mines, Department of Lands and Mines, Edmonton (1937).

Canadian Mineral Industry in 1937, Mines and Geology Branch, Department of Mines and Resources, Ottawa.

Canada Year Book, 1938, Dominion Bureau of Statistics, Department of Trade and Commerce, Ottawa.

COAL

110. **Origin of Coal.**—On page 34 the formation of coal beds by the filling in of lakes was explained. But swamps and broad flat plains in river valleys and coastal plains may also develop beds of peat which in time become coal. In all these cases coal was formed from vegetation which grew there. But it has also been suggested that coal may have been formed from vegetation which was transported to areas, such as deltas, where it accumulated and in time formed coal. It is estimated, however, that the amount of coal formed from such drift vegetation is small, and it is evident that most coal has been formed where the vegetation grew. No tropical climate was required for the profusion of vegetation in the coal forming ages, but abundant moisture was necessary.

It has been calculated that about twenty feet of vegetable material (peat) would be required to make one foot of coal. This is a rough estimate, for it does not take into consideration the kind of vegetable material and the kind of coal.

111. **Grades of Coal.**—When vegetable matter is covered by water it is gradually changed chemically by microbian action into hydrocarbons (compounds of carbon and hydrogen). The microbes act first on the easily decomposable substances such as protoplasm and carbohydrates, then on the more resistant substances such as bark, gums, cone scales, etc., and waxy and resinous materials. The longer the microbes are able to act on the organic matter, the greater will be the proportion of fatty, oily, and waxy hydrocarbons in it; and hence the higher will be the grade of peat (and coal) produced from it.

In due time the pressure on the peat deposit consolidates it into coal and drives off variable quantities of water and volatile gases, which escape through fissures and fractures in the overlying strata. The peat will be subject to different degrees of pressure; and the greater the pressure applied, the greater will be the proportion of the more solid hydrocarbons to the other constituents of the coal, and the higher will be its grade or rank. As extremely great pressures are exerted in folding of the strata, it is expected that these folded rocks will contain the highest grades of coal, viz., bituminous and anthracite, and that lignite will be found in plains where little or no folding has occurred.

Coal is graded by chemical analysis, based on four constituents of coal, viz., moisture, ash, volatile matter, and fixed carbon. This last depends on the amount of hydrocarbons in the coal, and it is very important in determining the kind of coal. When a sample of coal is burnt, the amount of heat it produces is measured in British Thermal Units (B.t.u.). A B.t.u. is the amount of heat required to raise the temperature of one pound of water 1° F.; the number of B.t.u. is generally given per pound of coal. It was noted on page 34 that in Alberta the highest grades of coal are found in the mountains and that the grades become lower towards the prairies. The following table gives chemical analysis of some Alberta coals:

Grade of Coal	% Moisture	% Ash	% Volatile Matter	% Fixed Carbon	B.t.u. per lb.
Semianthracite	1.8	8.4	10.8	79.0	13,990
Bituminous	1.2	9.3	24.2	65.3	13,740
Sub-bituminous	9.4	8.0	31.7	50.9	11,900
Domestic (lignite)	16.2	7.0	33.5	43.3	9,940

Note that the heating value (number of B.t.u.) increases as the percentage of fixed carbon becomes greater and as the percentages of moisture and volatile matter decrease.

A standard classification for grading coals in Canada and United States has been worked out by scientists of the two countries and was adopted in 1937, but is not yet in common use in Canada. Although this mode of classifying coals is rather complicated, under it Alberta coals would rank higher than at present; e.g., our domestic or lignite coal would be given sub-bituminous ranking.

112. **Coal Fields of Alberta.**—Practically all coal in Alberta is produced from three formations: Kootenay, Belly River, and Edmonton. Some coal is produced from the Tertiary, but it is relatively unimportant. There is no coal in the Carboniferous formations of the Rocky Mountains, for marine conditions prevailed there in that period.

Bituminous coal of Kootenay age is produced in the front ranges of the Rocky Mountains, being mined extensively at Coleman, Blairmore, Bellevue, and Hillcrest in the Crowsnest Pass area, and northwards at Canmore, Nordegg, Cadomin, Luscar, and Mountain Park. Burmis, Frank, and Passburg in the Crowsnest Pass and Brule and Pocohontas in Jasper Park were once important mining centres. In some places it is semianthracite. The quality of the coal is no

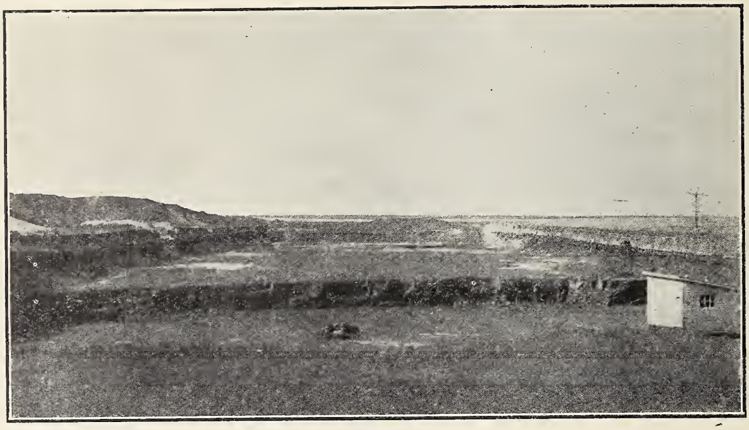

FIG. 99

Strip mining at Sheerness; pit of the Leavell Coal Co. showing the working face of the coal seam (lower dark band) and the depth of overburden removed.

doubt largely due to the intense folding and faulting that accompanied the raising of the Rocky Mountains. In many places the coal has been crushed into lenticular fragments. It is probable that during faulting, slipping took place along these coal seams, that is, they acted as fault planes. In addition to improving the quality of the coal, the raising of the mountains brought coal seams close to the surface. Pressure from the west during the mountain-building movement threw the strata into anticlines and synclines with faults here and there. In most cases the anticlines have been removed by erosion; hence the coal is mined in synclines. In Fig. 98 notice that the crest of the anticline betwen Hillcrest and Blairmore has been eroded off.

Sub-bituminous coal is mined from the Belly River and Saunders formations in the foothills at Pekisko, Priddis, Saunders, Coal Valley, Sterco, Prairie Creek, and formerly Coalspur. It has not been subjected to the intense pressures that acted on the coal further west, and consequently is less mature and of lower grade.

Lignite (called "domestic" in Alberta) is mined on the plains. Lignite coals have not been subjected to great pressure and are younger; they are, therefore, of lower grade than the coals mentioned above. These coals are of better quality as the seams get deeper, for the presssure on them is great. The principal mining centres for Belly River coal are Lethbridge, Taber, and Redcliff. Edmonton formation lignite is mined chiefly at Drumheller and district and at Sheerness, Tofield, Edmonton, and Sturgeon Valley. At Sheerness and Tofield the coal lies so close to the surface that strip mining is practised, that is, the overburden or surface layer of soil is removed by steam shovels and the coal then dug out (Fig. 99).

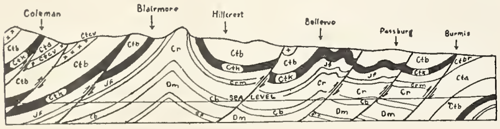

FIG. 98

Section in Crowsnest Pass to show the structural relations of the Kootenay coal measures (black); horizintal distance represented is about 10 miles; Cf Flathead quartzite (Cambrian), Dm Minnewanka limestone, Cb Banff shale, Cr Rundle limestone, Crm Rocky Mountain quartzite, Jf Fernie shale, Ctk Kootenay coal measures, Ctb Blairmore sandstone, Cta Alberta shale, Ctbr Belly River sandstone; note the synclinal structure of the coal basins.

113. **Production and Reserves.**—It has been estimated that the total available coal in Alberta is 40,200,000,000 tons, and of this 50% or about 20,000,000,000 tons is minable and recoverable. In spite of the abundance of coal in Alberta, Canada imports about 50% of her annual consumption of thirty million tons. It is unfortunate that the large reserves in Alberta are so far from populous centres of eastern Canada.

In 1938 Alberta produced 5.230,025 tons of coal, valued at $13,702,983. Of this quantity 2,287,850 tons were bituminous of Kootenay age, 488,912 tons were sub-bituminous of Belly River age, and 2,453,263 tons were lignite (domestic) of Belly River and Edmonton age. Alberta ranks second in coal production in Canada, being exceeded only by Nova Scotia, which has a slightly greater production.

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PETROLEUM AND NATURAL GAS

114. **Definition of Petroleum.**—Petroleum is defined as a mixture of oily hydrocarbons that exudes from the earth or is pumped up. When the mixture is distilled, it yields over 1,000 products, the most important being gasoline, benzine, kerosene (coal oil), fuel oil, lubricating oils and greases, paraffin wax, and asphalt.

The proportion of each of these constituents to the whole mixture varies with each field and even in each well in an oil field. An oil containing high percentages of gasoline and other light oils is a **high gravity** oil; an oil having large percentages of asphalt, paraffin, etc., is a **low gravity** oil. The gravity is usually stated in degrees A.P.I. (American Petroleum Institute); the scale reads from 1° to 100°. The higher the A.P.I., the higher the gravity, and the better the price the oil will bring. Turner Valley oil of about 47° A.P.I. is 50% gasoline, and Wainwright oil of about 20° A.P.I. is 2% gasoline; gasoline is from 55° A.P.I. up.

115. **Origin of Oil.**—It is generally accepted that oil and gas have been formed from the remains of plants and animals which were buried in the clays and sands along sea coasts and in bays, swamps, and lakes. The vegetable matter may have been seaweed, diatoms, and fresh water plants; and the animals corals, oysters, clams, foraminifera (globigerina belongs to this group), and fish. This matter was covered over by other sediments, which along with salt water protected it from oxidation. Then the action of bacteria, chemical action, pressure of overlying strata, lateral pressure exerted in folding, and heat—all combined to produce changes in the organic matter; as a result petroleum and gas were distilled off. The petroleum and gas accumulated in **oil pools** or **fields.**

114. **Accumulation.**—As the oil and gas were formed from this organic matter, they, being lighter than the water in the sediment, would rise through the pore spaces in the rock until they encountered an impervious layer of rock, such as shale. There they would collect: gas, the lightest, at the top; then oil; and water below. If a fold or anticline were present the gas and oil would drain **upwards** into it (Fig. 100), and the accumulation might be large enough to be profitably exploited. An anticline is a common type of reservoir for oil and gas accumulation, but other geological structures serve the same purpose. One of these is a dome, in which the strata dip away from a point, instead of from a line as in an anticline.

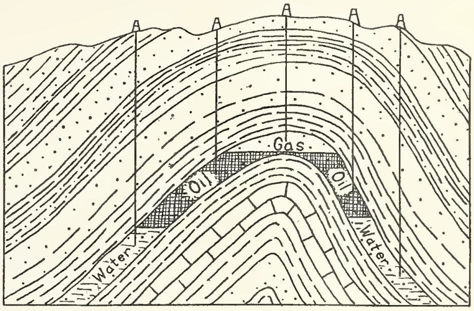

FIG. 100

Section of an anticline to show the relative positions of gas, oil, and water in the porous horizon (or oil sand). The well in the centre produces gas; the two on each side of it, oil; and the two outer ones, only water.

The oil does not collect in a hollow as water does in a pool, for there are no large empty spaces at depth; but it simply occupies the spaces between the particles of sand, or cavities in the limestone or dolomite or other rock. The zone of oil-saturated rock, whether it be sandstone, limestone, etc., is known as an **oil sand.** The pore spaces in the sand (i.e., **porosity**) may be from 15 to 40% of its volume. Hence if the porosity of the rock and the thickness of the sand are known, then the amount of oil in the sand per acre can be calculated. This is one method of estimating oil reserves, e.g., the estimated oil reserves per acre for an oil sand 40 feet thick and having a porosity of 35% $=43{,}560 \times 40 \times 6\frac{1}{4} \times 35\% = 3{,}811{,}530$ gals. or $3{,}811{,}530 \div 35 = 108{,}900$ barrels (43,560 sq. ft. = 1 acre; $6\frac{1}{4}$ gals. = 1 cu. ft.; 35 gals. = 1 bbl.)

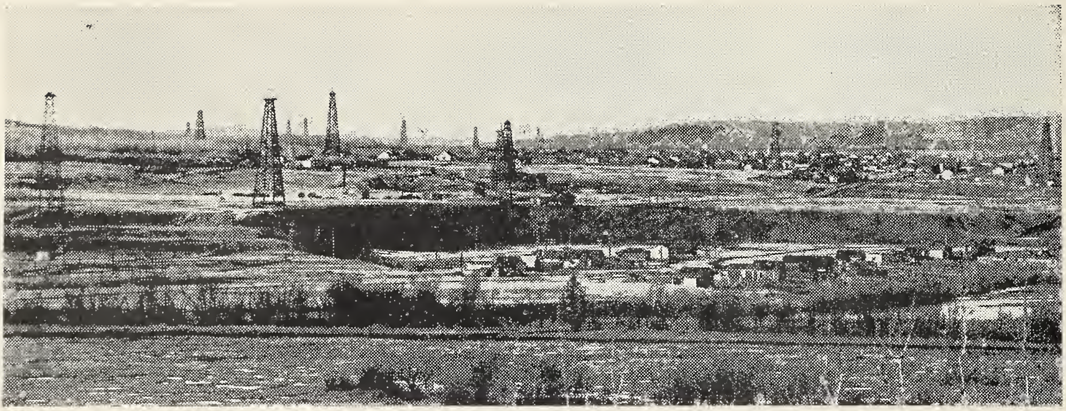

FIG. 101

View of Turner Valley looking north towards the town; the ridge on the right is composed of east-dipping Belly River strata and forms the east limb of the anticline; the west limb can be seen in the distance to the left. The valley is at the crest of the anticline but the Belly River and higher formations have been removed by erosion exposing Alberta (Benton) shales. The wells shown are gas producers, the developed crude areas being northwest and southeast of here.

(Photo by H. Pollard, Calgary, Alberta)

117. **Indications of Oil.**—The oil prospector looks for certain signs of oil in an area before leasing land and commencing to drill. Some of the indications are: (1) seepages of wet gas (natural gas containing oil); (2) oil seepages; (3) presence of oil saturated rocks; (4) mud volcanoes activated by gas, not steam (page 59); (5) suitable structure for oil accumulation close to a known or **proven** oil field. This structure might be worked out and studied by noting how the rocks dip at the surface, or by core-drilling to a key bed. A well being drilled in an entirely new area in order to explore its oil possibilities, is known as a **wildcat.**

Very often an irridescent film on water in springs, wells, muskegs, etc., is mistaken for oil, but it is only an iron compound. It can be readily distinguished from oil by touching it, for it breaks up into angular fragments, whereas oil will not break up.

118. **Drilling Methods.** — Oil wells vary in depth from a few hundred feet to many thousands. The deepest oil well is in California. It is 15,004 feet deep (almost three miles) and cost about $500,000 to drill. There are two kinds of drills in common use, the **standard cable tool rig** and the **rotary drill.** The standard rig uses the percussion method, i.e., that of dropping a heavy iron weight called the **bit,** which pounds its way downwards by pulverizing the rock. By the rotary method a bit is rotated rapidly, and this action breaks up the rock into small fragments. These fragments are carried out of the hole by the **drilling fluid,** a mud of about the consistency of thick soup, which is kept circulating to the bottom and up. The pieces of rock are strained out, and the fluid is used over and over again.

119. **Relation of Oil Production to Gas Pressure.**—In a flowing oil well the natural gas in solution provides the expulsive force for the oil; therefore the amount of oil which can be recovered from the oil sand will depend on the amount of gas and how it is conserved. In some oil fields only about 20% of the total oil was brought to the surface, because gas pressure was wasted in recovering the oil. It is important then to conserve the gas, for without it pumping has to be employed, and this method does not recover as much oil. By judicious use of the gas, about 95% of the oil has been recovered in some fields. In some fields it was considered economical to shut down some of the wells which produced too little oil for the amount of gas required to lift that oil to the surface. As gas is used and oil taken from the structure, water moves up the limbs or flanks of the anticline to take its place (Fig. 100). This water encroachment ultimately brings about the death of the field.

120. **Turner Valley Oil Field.**—This is preeminently the principal producing field in Canada. In 1938, it produced 6,691,075 barrels of oil. In the same year Ontario produced about 168,000 barrels, New Brunswick about 24,000, and Fort Norman about 10,000 barrels—the last supplying the needs of the northern mines. Most of the oil used in Canada is imported from the United States. Canada produces about 15% of her needs.

Turner Valley lies about thirty-five miles southwest of Calgary (Figs. 97, 101). So far, the oil-producing part of the field, the west flank of the anticline, has been shown to be at least seventeen miles long and about a mile wide. Gas seepages first attracted attention to Turner Valley as a probable oil field. In 1913, a well was drilled and gas discovered. Other wells were drilled and some produced a high gravity crude oil from the Blairmore formation. In 1924, a well was drilled into the Palaeozoic limestone, and wet gas having a high gasoline content was struck. From 1924 to 1936 Turner Valley was a wet gas field and produced naphtha (crude gasoline), which was extracted from the gas. In 1936, another important discovery was made, for crude oil was found, and since that time it has been the object of every drilling venture.

The oil wells are capable of producing from a few barrels up to about 3,000 a day, but are prorationed, that is, they are held down to a production which just meet the needs of the market. Each well is allowed to produce a certain proportion of the market requirements, and thus a price-cutting war is averted. Only one well can be drilled on each 40 acres (a legal subdivision). The reserves are estimated to be 200,000,000 barrels, and the life of the field is put at thirty years. The oil sells in the field at about $1.20 per barrel of 35 imperial gallons, but this price increases according to the gravity of the oil—the higher the gravity, the higher the price. Three pipe lines carry the oil from the field to Calgary, where much of the oil is refined.

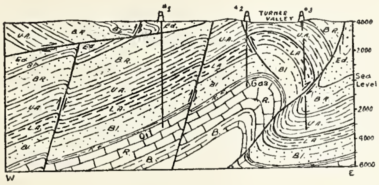

FIG. 102

Generalized section of the Turner Valley anticline; horizontal distance represented is 4½ miles; B Banff shale, R Rundle (Madison) limestone, KF Kootenay and Fernie formations, Bl Blairmore sandstone, LA Lower Alberta (Benton) shale, UA Upper Alberta (Benton) shale, BR Belly River sandstone, Bp Bearpaw shale, Ed Edmonton sandstone.

The principal oil sand is the upper 500 to 600 feet of the Rundle limestone (called by oil men the **Madison,** by which name it is known in the United States). The structure of the reservoir or oil pool is an anticline that, on the east flank, has been dragfolded, i.e., pushed over so that one side of it is broken off (Fig. 102). Notice in the diagram that the Palaeozoic limestone has been thrust on to the younger Mesozoic strata on the east. The anticline has faulted considerably, but many of the faults do not show at the surface, and the structure is much more complex than has been illustrated. Well No. 2 at the crest of the anticline produces wet gas; Well No. 1 is a crude oil producer; Well No. 3 has been drilled too far east and has missed the limestone. The boundary between oil and water, or **edge water,** occurs at about 9,500 feet below the surface.

The depth of most of the wells is between 7,000 and 8,000 feet, and the cost of each is about $150,000. About six months are required for the drilling of a well by a rotary drill.

121. **Other Oil Fields.**—Crude oil is also produced in the Red Coulee and in the Wainwright oil fields. Strong indications of oil have been found in wells drilled at Lloydminster, Dina, and Fabyan, but this area requires more exploration in order to locate larger pools. The Red Coulee field (near the international boundary) is the extension of the Montana oil fields into Canada. At Peace River, Steveville, and many other places, strong "shows" of oil have been obtained. There must be other oil fields in the foothills which await discovery; for it is not reasonable to conclude that in all the hundreds of miles of foothill country in Alberta only one little strip about 17 miles in length, viz., Turner Valley, should carry oil and gas.

122. **Occurrence of Natural Gas.**—Oil deposits are generally associated with gas, but gas is not always associated with oil. Gas is much more mobile than oil and may travel longer distances from the source; besides, heat may have decomposed the oil to gas.

123. **Gas Fields of Alberta.**—There are many gas fields in Alberta, some of the more important being Milk River, Red Coulee, Foremost, Bow Island, Medicine Hat, Brooks, Turner Valley, Viking, Kinsella, Fabyan, Wainwright, Pelican Rapids on the Athabaska River, and Pouce Coupe. Calgary is supplied with gas from the Turner Valley field, and Edmonton gets gas from the Viking field. Many cities and towns, such as Medicine Hat, Brooks, and Wainwright are able to get gas locally.

In 1936-37, Alberta used 18,727,496 M (thousand) cubic feet of gas, having a value of over $4,500,000. In the same period in Turner Valley 1,415,520 barrels of oil valued at about $3,000,000 were produced from 74,710,000 M cu. ft. of gas, most of which was then wasted. This gas would have a market value of about $10,000,000.

The consumption of gas in Ontario is about one-half that of Alberta's.

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Numerous reports may be obtained from Ottawa dealing with the geology of particular areas; Dr. Hume's "Oil and Gas in Western Canada" contains about all the general information required about any region, and may be obtained on request.

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METALLIC ORE DEPOSITS

124. **Introduction.**—Deposits of ores or metals are rare in Alberta, and with the exception of gold none has been developed on a commercial scale. The Rockies carry very little mineral matter of this type, but small deposits or "pockets" of metallic ores have been found. There are deposits of copper and lead west of Banff, but these are too small to warrant development.

125. **Gold.**—There are two kinds of gold mining, **placer** and **lode.** In placer mining the gold is in the form of flakes, grains, and nuggets, and is separated from mud, sand, and gravel by washing in water; hence the term, "panning for gold." The gold originally came from hard rocks, which were broken down by weathering and erosion. In lode mining the gold is present in hard rock, and such rock must be crushed before the gold can be extracted. Placer mining can be carried on with no more equipment than pan and shovel, but lode mining requires elaborate and expensive machinery.

Alberta produces only small quantities of gold from placers. In 1937, gold production was 46 ounces, worth $1,609, a negligible amount compared with Canada's production of 4,095,872 ounces, worth $143,314,561. Alberta's gold was obtained from banks and beds of streams. It is in very small particles with rounded edges and is called "flour" gold, and it requires special care to separate it from mud and sand. The North Saskatchewan, McLeod, and Athbaska are the principal rivers that have been panned for gold.

The direct source of gold is thought to be the **Saskatchewan gravels and sands**, which may be of Oligocene or later Tertiary age. These gravels and sands lie upon bed rock (sometimes the Edmonton formation), and are covered in places by glacial drift; therefore they must have been deposited before the Pleistocene ice age. They probably originated in the Rocky or Selkirk Mountains, and rivers and streams spread them eastward over the plateau in the same manner as the Cypress Hills formation (page 68), and at the same time or not long after. Hence the original source of the gold was in the mountains to the west, most likely the Selkirks. It could hardly have been brought in by continental glaciers from the north or northeast, for then it would be coarse and more erratic in distribution. The fineness of the gold, viz., 350 to 450 particles or "colours" to the cent (20 dollar gold), is good evidence that it has been worked over more than once.

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126. **Iron.**—The abundant coal resources of Alberta along with the unlimited supplies of limestone would sustain an important iron industry if iron ore were present in commercial quantities either in this province or in eastern British Columbia. To operate successfully, large reserves of ore averaging about 40% iron are necessary.

Iron occurs in Alberta in the following forms:

(1) Ironstone nodules. — These occur in shales as more or less rounded stones scattered throughout its beds or in thin streams. Sometimes they test 50% (or more) iron, but are too erratic in distribution to serve as a source of ore. Ironstone is fairly plentiful in the Upper Cretaceous formations.

(2) Iron formation.—Iron occurs in the Precambrian rocks near Goldfields, Saskatchewan, but the percentage of iron is too low for development.

(3) Iron Springs.—Water rich in iron has built up in some places deposits of bog iron ore, but none of these are large enough to be commercially valuable. Generally associated with

these deposits are tufa and a black substance called **wad,** a compound of manganese.

(4) Magnetic sandstone.—Near Burmis (Fig. 97) in the Crowsnest Pass district, iron-bearing sandstone occurs in the Belly River sandstone. It is considered to be an old beach deposit. It tests as high as 55% metallic iron, but the deposit is too small to be of value. The iron occurs as **magnetite,** the magnetic ore of iron.

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127. **Zinc.** — An occurrence of sphalerite (zinc sulphide) at Eldon, fifteen miles west of Banff, was opened up, but was found to be too small to warrant further development. Pockets of zinc ore have been reported from other places.

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NON-METALLIC ORE DEPOSITS

128. **Bentonite.**—This is a clay, creamy to dark green in colour, and probably formed by the decomposition of volcanic dust and ash. It absorbs water to three times its own volume and becomes soft with a soapy feel. It is used in the preparation of moulding sand, as a filler for yarns and paper, as a cleanser of cloth and oils, as a constituent of some soaps, salves, and cosmetics, as a suspending agent in enamels, horticultural sprays, and insecticides, to clarify wines and honey, and in the preparation of cements, plasters, and drilling fluid. It varies in price from $7.50 to $60.00 a ton, according to the treatment it has undergone in order to adapt it for a particular use. Most of the bentonite used in Canada is imported from the United States, as our local deposits are not extensively developed.

Bentonite occurs in thin seams in the Upper Cretaceous strata of Alberta. A deposit near Drumheller occurring in the Edmonton formation is used in making drilling fluid for oil wells in Turner Valley. A seam near Edson was mined for a time and used in the preparation of toilet goods. It is a constituent of gumbo and gives it its adhesiveness and slipperiness.

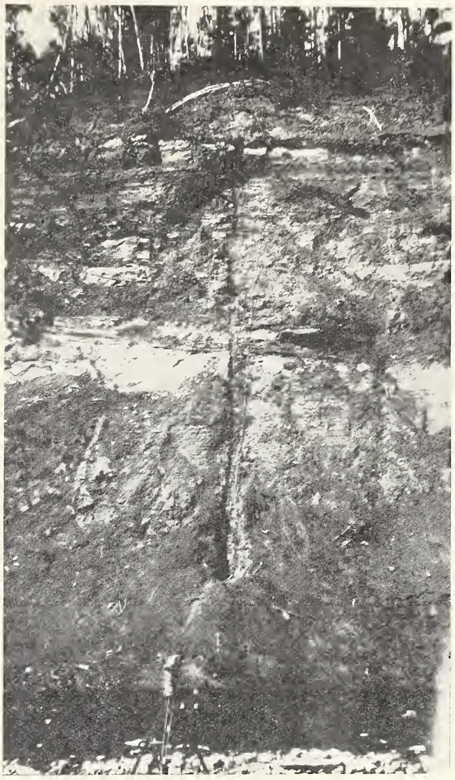

FIG. 103

Bituminous sandstone exposure at McMurray with a trench dug into its face for examination and sampling of strata.

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129. **Bituminous Sands.** — Bituminous sands, or **tar sands,** may be described as a sandstone of which the cementing material is bitumen instead of silica, lime, or iron oxide (bitumen is a mixture of petroleum and asphalt). The bituminous sands are dark brown to black in colour on account of the bitumen, for the sand itself is white. It is believed that the McMurray tar sands were once an oil pool which has since been laid bare by erosion, and from which the more volatile constituents such as gasoline have been evaporated.

The tar sands of Alberta occur in the neighbourhood of McMurray, some 300 miles northeast of Edmonton. They are exposed along the banks of the Clearwater River near its confluence with the Athabaska, and then down the Athabaska River for about sixty-five miles (Fig. 103). The bituminous sandstone is from fifty to one hundred feet thick, and exposures of it indicate that it underlies an area of at least 750 or 1,000 square miles, and probably as great as 15,000 square miles. Only a small part of this vast quantity is available, for in some places the overburden (the covering soil and rock) is too thick to be removed profitably.

Probable uses of bituminous sands are for paving and as a source of oil for fuel or for treating roads. In 1912 and 1914, small shipments of these sands were made to Edmonton and used in paving. These sections are still in place; therefore it is quite suitable for this purpose. When treated for oil content, from fifteen to forty gallons per ton have been recovered, as the bitumen content varies from place to place. The cost of such oil is $2.10 per barrel laid down in Edmonton—a price too high to compete with Turner Valley, Wainwright, and Lloydminster crude. In 1938 a plant operating at Bitumount, forty miles north of McMurray, extracted from the sands 1,627 barrels of asphalt, valued at $6,000 and 1,282 barrels of oil valued at $4,487; the oil was shipped north to the mines in the Northwest Territories. No shipments of bituminous sand for paving purposes were made.

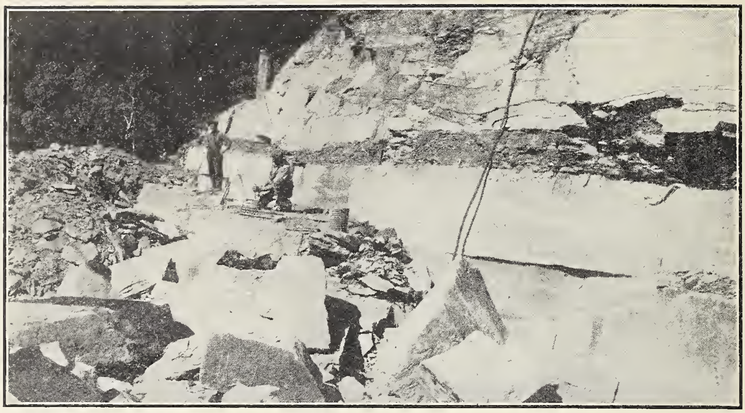

FIG. 104

Paskapoo sandstone in Oliver quarry in valley of Bighill Creek, north of Cochrane, Alberta; this sandstone was quarried for use in the construction of the Mounted Police Barracks, Calgary.

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130. **Building Stones.**—Only a small part of the building stone used in Alberta is quarried within the province. A good building stone possesses the following characteristics: durability, pleasing appearance, ease of cutting and chiselling in shaping, bedding planes along which it readily splits, proximity to markets. In 1937, only 13,225 tons of building stone, valued at $27,789, were quarried in Alberta.

A coarse sandstone of the Corral Creek formation has been quarried a few miles east of Lake Louise station. Though durable it weathers brownish, which is not a desirable feature. Small amounts of Precambrian boulders have been used for ornamental purposes, such as walls and foundations. The St. Piran quartzite has been found too hard to work. The chalet at Lake Louise was to have been constructed of this rock, but plans were changed for that reason. As a rule the Cambrian and Devonian limestone are too badly fractured, too hard to work, and contain too many nodules and seams to be of value. The thin-bedded Triassic limestone of the Spray River formation has been used extensively at Banff as constructional material, being used in the Banff Springs Hotel, the Administration Building, the Bow River Bridge, "Cave and Basin," and other Park buildings. At Castor, sandstone of the Edmonton formation has been used in school and bank buildings, the stone being taken from a local quarry.

Paskapoo sandstone has been quarried fairly extensively at Entwistle, Red Deer, Calgary, Cochrane (Fig. 104), High River, Macleod, Monarch, and other places, but only the quarries at Calgary, Cochrane, and Monarch are now active. This stone deteriorates rather rapidly. The Parliament Building at Edmonton, and in Calgary the City Hall, Natural Resources Building of the Canadian Pacific Railway, and the Y.M.C.A. Building are constructed of it. Facings on residences of the University of Alberta are of this stone.

Tyndall limestone of Ordovician age is a popular building stone on the prairies. It is quarried near Winnipeg at Tyndall. The Post Office in Calgary, and four outstanding structures in Edmonton, the Bank of Commerce, the Hudson's Bay Company's store, the T. Eaton Company's store, and the Administration Building, are constructed entirely of this limestone, and many other buildings in the province are trimmed with it. It is light grey, almost white, and has a mottled appearance; on close examination fossils of many animals, such as corals, bryozoa, gastropods, and cephalopods, can be seen in it.

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131. **Cement.**—The raw materials used in the manufacture of cement are shale and limestone; the product is called **Portland cement,** which when mixed in proper proportions with sand, gravel, and water, makes concrete. The only plant operating in Alberta is at Exshaw, west of Calgary. It uses Palaeozoic limestone and Upper Alberta shales. In 1937, it produced 267,106 barrels (each of 196 lbs.) valued at $531,541.

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132. **Clay Products.**—In 1937, Alberta's production of clay products (bricks, hollow tile, sewer pipe, crocks, stoneware, art pottery, etc.), was valued at $338,638. The centre of this industry is in Medicine Hat, for it is close to supplies of clay, and also fuel (natural gas) is cheap.

Unconsolidated surface clays deposited by rivers or lakes are used for bricks and hollow tile, but for finer clay products, such as stone jars, tea pots, etc., special clays are required and are brought in from southern Saskatchewan to the factories at Medicine Hat. At Redcliff shales of Belly River age are used in the manufacture of bricks. Shales of the Edmonton and Paskapoo formations have been used for brickmaking elsewhere with satisfactory results.

The clays and shales of Alberta are of such great extent and variety that considerably more exploration and testing will have to be done in order to determine the products for which the clays are best suited.

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133. **Gravel and Sand.**—Alberta is well supplied with this material, so necessary to the builder in surfacing roads and in constructional work requiring concrete. A great deal of gravel is quarried in the valleys of rivers and streams. On the plains and in the mountains glaciers have left huge piles of glacial drift, much of which can be applied directly to roads or used for other purposes with very little re-sorting except to pick out the boulders. In 1937, the production of gravel and sand in Alberta was 711,966 tons valued at $312,687. The glass works at Redcliff import glass sand from Manitoba and Illinois.

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134. **Graphite.** — Graphite is composed of pure carbon. It is soft, iron black in colour with a metallic lustre, and has a soapy feel. It generally occurs in flakes. It is used in foundry work, and for making lubricants, paint, stove polish and "lead" pencils. Ontario alone produces graphite in Canada. The price varies from $12 to $400 a ton, according to grade.

Graphite was found in the Precambrian schists a few miles southwest of Jasper, but the deposit is of too low grade to be profitably worked. The graphite is probably derived from carbonaceous shales (Fig. 97).

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135. **Gypsum.**—Gypsum is a mineral composed of calcium, sulphur, and oxygen combined with water. It is heated to drive off the water and is then known as **Plaster of Paris.** Gypsum is generally white in colour, and is fairly soft, being easily cut with a knife or crushed to a white powder. It frequently occurs with rock salt. It is also found in some shales in the form of transparent crystals, in which case it is known as **selenite.** It is a marine precipitate, having been deposited by concentrated sea waters along sea margins. These waters vary in concentration, since beds of gypsum generally alternate with beds of salt and limestone. **Alabaster** is a pure form of gypsum used in sculpture. **Anhydrite** is a form of gypsum without the water. It sometimes occurs with gypsum.

Gypsum is used extensively in the building trades for making wallboard tiles, plaster, and fire-resisting blocks. It is also used in making sulphuric acid, and as a fertilizer. It sells for about $1.50 a ton. Nova Scotia is the largest producer in Canada, but New Brunswick, Ontario, Manitoba, and British Columbia also mine it.

It occurs in Alberta in a number of places, but as yet none of these deposits have been exploited. The largest deposit occurs at Peace Point on Peace River, in the extreme northern part of the province. The gypsum beds are part of the Fitzgerald dolomite, which is of Silurian age. It is estimated that there are about 217,000,000 tons in the deposit. The gypsum is of a good quality and favourably situated on a water route (Fig. 97).

Another deposit, Triassic in age, occurs near Jasper, northwest of Brule Lake. This deposit is large enough to be of commercial value. Gypsum beds have been encountered in drilling oil wells on the prairies, but they are too deeply buried and too thin to be worked. In drilling for salt at McMurray, engineers find that the core shows thick beds of gypsum at comparatively shallow depts. In some of the shale formations, such as the Bearpaw, gypsum occurs as crystals of selenite, and these are quite plentiful at some horizons, but not enough to be of commercial value.

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136. **Lime.** — Lime or quicklime is a white substance obtained by burning limestone, carbon dioxide being driven off in the process. Pure limestone is necessary to produce good lime. Lime is used to make plaster for building purposes. It sells for about $8.00 per ton, but this price will vary according to transportation charges. In 1936, Alberta produced 10,651 tons valued at $93,478.

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137. **Phosphate Rock.**—In 1397, 113,971 tons of phosphate rock were imported into Canada; nearly all of it came from Florida and Montana. The value of it was $453,599. Most of the rock was made into fertilizer, but some of it was used in the manufacture of compounds of phosphorus, which are used as cleansers, in laundering, tanning, photography, and sugar refining. The smelter at Trail, B.C., imports phosphate rock from Montana for the production of fertilizer. In the Rocky Mountain Quartzite at Banff there is a thin seam of phosphate rock of varying thickness up to eighteen inches thick. Bones, teeth, and scales of fish are found in it, and indicate its origin. The seam is too small, however, to be mined economically. In the Crowsnest Pass area there are also deposits, but they are of too low grade to compete with the Montana product.

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138. **Sodium Chloride (Common Salt).** — Common salt or rock salt is the mineral **halite.** Individual grains of salt are tiny cubes, which when pure are transparent. It is composed of sodium and chloride. The chief sources of salt

are salt beds deposited by evaporation of salt water of the ocean and inland seas, such as Great Salt Lake and Dead Sea. Some salt is obtained from salt springs. As it is readily soluble in water, salt deposits are generally thickly covered by sediments, which have protected them from solution by ground water. The mineral is recovered by forcing water into a deposit which is deeply buried and evaporating the brine, or it is sometimes mined by driving shafts to the beds, if they lie at shallow depths.

The uses of salt are many, for, besides being an important item of diet, it is used as a preservative of meat, fish, butter, and vegetables, for surfacing gravel roads, as a source of chlorine and sodium for compounds of these substances, for curing hides, for putting a salt glaze on pottery, for preventing the cracking of bricks in drying and firing, for refrigerating purposes, and in the metallurgical industry.

The production of salt in Alberta has only begun, even though there are large deposits of the mineral in the province. Recovery of salt was begun at Waterways in 1937; and in 1938, production was 3,994 tons, valued at $39,940. At this place the salt beds were located by core-drilling. One of the beds is 199 feet thick and occurs at a depth of 694 feet. It has been estimated that this bed contains enough salt to supply all Canada for the next sixty years, assuming the consumption to be 500,000 tons annually. Recovery of the salt is accomplished by forcing cold water into the bed, pumping up the saturated brine, and evaporating it in large pans 110 feet long and twenty-five feet wide.

In the very northern part of the province along Salt River there are saline springs, which issue at the base of an escarpment of Fitzgerald dolomite. Salt crystallizes as the water flows out and along the ground, and as much as 400 tons of salt have been noted there at one time. Some of the salt has been used for the northern trade.

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139. **Sodium Sulphate (Glauber Salt).**—This is a white salt that is precipitated by evaporation in many lakes in Western Canada. Most of the production is in Saskatchewan. In 1937, 79,884 tons, valued at $618,028, were produced in Canada; Alberta produced eighty tons, worth $480. The salt is used chiefly in the manufacture of paper and pulp and in metallurgy; hence most of the product is shipped to eastern Canada.

Deposits of this mineral are few in Alberta. There is one deposit near Minburn, 100 miles east of Edmonton. It is estimated that it contains about 100,000 tons of salt. It covers about thirty acres and is about ten inches thick.

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140. **Talc or Soapstone.**—Talc is a soft mineral having a soapy feel and generally a greenish colour. It is used in the manufacture of paint, rubber, roofing, textiles, paper, cosmetics, and lubricants. It is worth from $9.00 to $100 a ton, according to grade, the finest quality being used for cosmetics.

No deposits have been found in Alberta, but a deposit west of Banff, on Mount Whymper, is just a few miles over the border in British Columbia. Should it be worked, development would take place from the Alberta side. The deposit is rather high in lime.

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141. **Water Power.**—The production of energy from falling water is of ever-increasing importance, and electricity produced in this way is as much a basic commodity as coal or any other fuel. Statistics are concerned as much in measuring its production as in the production of coal, oil, etc., and undeveloped water power is considered as much a source of raw material as uncut forests and unmined coal.

Electricity is developed by dynamos operated either by running water or steam turbines. Electricity developed by running water is called **water power** or **hydro-electric power,** and is produced where streams have rapids or falls. Electricity developed by steam plants is produced from coal or other fuel. The development of hydro-electric power requires an even flow of water the year round, but as this is not found in Alberta, dams have to be constructed to ensure this. The dams are, of necessity, constructed in the mountains or foothills where suitable storage basins and steep gradients or rapids or falls are found.

It has been estimated that 390,000 hydro-electric H.P. could be developed, in Alberta. Of this, 71,597 have been developed to 1938, and practically all of this development has been in the Bow River basin. The hydro-electric plants on this river at Kananaskis, Horseshoe Falls, and Ghost River are capable of producing 67,600 H.P. Development of hydro-electric in Alberta has lagged behind the development of electricity by steam power for the following reasons:

(1) Proximity to coal fields.—On account of the low cost of coal electricity can be developed in many places as cheaply by steam as by hydro-electric works. Only hydro-electric power that is developed at low cost can compete with it.

(2) Few industries.—Industries are the largest consumers of hydro-electric power, and Alberta is not an industrial province. Industries arrange to take the power during the daytime, when the demand for it is low.

(3) Uneven flow.—The greatest demand for power is in the winter, when daylight is short, but at this time the water supply is lowest. This disadvantage can only be overcome by the construction of expensive dams.

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Questions:

1. (a) Define mineral deposit.
   (b) State six important factors which determine whether a mineral deposit can be profitably developed.
2. (a) What are four advantages of diamond drilling?
   (b) Describe briefly the method of diamond or core-drilling.
3. (a) Name four places where peat beds may form.
   (b) How many feet of coal would be necessary to make a six-foot seam of coal?
4. (a) Explain the part played by microbian action in the formation of coal.
   (b) What part has pressure played in coal formation?
   (c) What is the most important factor in determining the heat value of coal?
   (d) What is a B.t.u.? Why should the number of B.t.u. be a consideration in purchasing coal? Calculate the number of B.t.u. per ton of the different grades of coals in Alberta (see page 101).
   (e) What components of coal are considered in coal analysis?
5. (a) Account for the distribution of the various grades of coal in Alberta in the mountain basins, foothills, and plains. To what formation or formations does each grade belong?
   (b) On a map of the southern half of Alberta block out the areas in which bituminous and semianthracite, subbituminous, and lignitic coals are mined. Name the important mining centres in each area.
   (c) What is strip mining? At what centres is it practiced? What two conditions are essential for it?
6. (a) At the 1940 rate of production, how long will Alberta's reserves of 20 billion tons last? Round off Alberta's production to the nearest half million tons.
   (b) Why does Canada import about half of her annual consumption of coal?
   (c) The following table gives the coal production of Alberta for the last 11 years. Draw a graph showing this information; put both graphs on the one sheet using a red line for the tonnage and a blue one for the value.

Year	**Tons**	**Value**
1930	5,755,911	$19,379,000.00
1931	4,564,290	13,415,745.00
1932	4,870,030	13,441,193.00
1933	4,714,784	12,197,339.00
1934	4,748,848	12,440,616.53
1935	5,462,973	13,946,338.15
1936	5,696,375	14,720,004.06
1937	5,551,682	14,434,969.75
1938	5,230,025	13,702,983.41
1939	5,518,105	14,454,324.87
1940	6,205,088	16,334,323.11

7. (a) Define petroleum.
    (b) Name five of the most important petroleum products.
    (c) What is the difference between "high gravity" and "low gravity" oil?

8. (a) Outline briefly the origin of petroleum.
    (b) Account for the accumulation of petroleum in pools.
    (c) Draw a diagram of an ideal oil structure, and show the gas, oil, and water horizons.
    (d) State three features of an oil sand.
    (e) Estimate the number of barrels of oil per acre in an oil sand 30 feet thick with a porosity of 35%. (35 gallons per barrel and 6¼ gallons per cubic foot; 43,560 square feet in one acre).
    (f) How much oil is obtained per acre in (e) if only 60% of the soil is recovered?

9. (a) What are four common indications of oil?
    (b) What is meant by a "wildcat" in oil prospecting?
    (c) Briefly describe the rotary and standard methods of drilling for oil.
    (d) What is the advantage of rotary drilling over the cable tool (or standard method)?

10. (a) Explain the movement of water in an oil field.
     (b) Why is it so important to conserve gas in an oil field? How is gas conservation affected?

11. (a) Make a sketch of the Turner Valley anticline. Show the gas and oil areas.
     (b) What is the principal producing sand in the Turner Valley field?
     (c) How is the field price of oil maintained in Turner Valley?
     (d) What oil field was discovered January, 1941? Where is it?

12. The following table gives the oil production in Alberta since 1923:

Year	Barrels	Value
1923	10,003	$ ______________
1924	14,049	______________
1925	168,643	______________
1926	219,598	______________
1927	332,133	______________
1928	489,531	______________
1929	999,152	______________
1930	1,433,844	______________
1931	1,455,195	______________
1932	917,622	______________
1933	1,013,040	______________
1934	1,265,940	3,031,446
1935	1,263,750	2,856,029
1936	1,320,442	2,915,380
1937	2,796,908	4,913,960
1938	6,742,039	8,638,926
1939	7,594,411	9,289,580
1940	8,493,527	10,504,669

Draw a graph to show this development of oil resources.

13. Give two reasons why gas is not always found with petroleum.

14. On a map of Alberta mark the important oil and gas producing areas.

15. (a) Distinguish between the two methods of mining gold.
     (b) Which of these methods is used in Alberta in obtaining gold?
     (c) Account for the presence of gold in Alberta.

16. (a) What are the three requisites for the production of iron?
     (b) Could the iron industry be established in Alberta? Explain.
     (c) Describe briefly one iron ore deposit in Alberta.

17. (a) What are the possibilities for producing bentonite in Alberta?
     (b) What are the principal uses of bentonite?

18. (a) What are bituminous sands?
     (b) What is the origin of the tar sands at McMurray?
     (c) What are possible uses of these tar sands?

19. (a) What are the principal features of a good building stone?
     (b) Which rock formations in Alberta have supplied building stone?

20. (a) What are the raw materials needed for the manufacture of cement?
     (b) How well off is Alberta for supplies of these materials? Explain.

21. (a) Why is Medicine Hat the centre of the clay products industry in Alberta?
     (b) What rock formations in Alberta have supplied shales for brick-making?

22. (a) Make a list of the possible sources of sand and gravel in Alberta.
     (b) For what two main purposes is gravel used?

23. (a) Name three forms in which gypsum occurs.
    (b) What are the most important uses of gypsum?
    (c) Explain briefly how deposits of gypsum originate.

24. (a) What are the most important uses of graphite?
    (b) Where is graphite produced in Canada?

25. (a) How is lime made?
    (b) What are its important uses?

26. (a) For what purposes is phosphate rock used?
    (b) What is the origin of the phosphate deposit at Banff?

27. (a) How are salt deposits formed?
    (b) Give fve important uses of common salt.
    (c) Describe the salt deposit at McMurray.
    (d) Describe a common method of recovering salt which is deeply buried.

28. (a) Where is the chief source of sodium sulphate in Canada?
    (b) What are the chief uses of this salt?

29. (a) Describe talc.
    (b) What are its uses?

30. (a) Give two reasons why dams for the development of hydro-electric power are generally located in the foothills or mountains.
    (b) Why has the development of hydro-electric power in Alberta lagged behind the development of electricity by other means?

31. On a map of Alberta mark the following:
    (a) The most important deposit of gold, iron, zinc bentonite, bituminous sands, building stone, gypsum, graphite, phosphate rock, common salt, sodium sulphate, and talc.
    (b) The area where the greatest hydro-electric development has taken place.
    (c) The centre of the clay products industry.
    (d) A cement manufacturing town.

Suggested Activities:

Diamond Drilling:

Obtain a piece of a diamond drill core; examine its mineral composition and its shape.

Coal:

1. Secure samples of lignite, bituminous coal, and anthracite. Powder about one gram of each, and test the relative amounts of moisture in each by heating separately in a test tube for three minutes. Keep the test tube horizontal, and observe the relative amounts of water that condense on the tubes. In order to obtain more accurate results weigh out definite amounts of each, heat in an open crucible, weigh again, and calculate the percentages of water.

2. In all probability there is a coal mine in your vicinity, and this information regarding it is easily obtained upon inquiry. What kind of coal does it yield? What are the percentages of ash, moisture, volatile matter, and fixed carbon in it? How many B.t.u. per pound are there? What is the annual production? What is the selling price per ton? What is the thickness of the seam? What is the depth of the seam below the surface? What is the length of the entry? Is the seam dipping or flat-lying? Does this make mining easier? How is the coal mined? What kind of rocks lie above and below the seam? Does water seep into the mine? Where does this water come from? Is there more water at certain seasons than at others? Make a cross-sectional diagram of the area about the mine, and show the seam or seams.

Petroleum and Natural Gas:

1. Obtain samples of low and high gravity crude oil, and note their colour and viscosity? What is the analysis of these oils? Obtain a small piece of the oil sand of the Turner Valley oil-field, or any oil-field, and note the sizes of the cavities in it.

2. Calculate the porosity of a piece of sandstone (about 50 c.c.). Put 100 or 200 c.c. of water in a suitably sized graduate or other vessel, place the rock in the water, and leave for 48 hours. Then remove the rock and calculate how much water has been absorbed by it. Now immerse the rock in a measured quantity of water to find its volume. The porosity of the rock will be the amount of water absorbed by the rock divided by the volume of the rock and multiplied by 100. Knowing the porosity of the rock calculate the number of barrels of oil in it per acre-foot (i.e., one acre in area and one foot thick).

3. The separation of gas, oil, and water into definite layers in an oil sand can be shown as follows. Measure out enough coarse sand to fill a large test tube within one inch of the top. Divide the sand in two equal parts, and wet one portion with coal oil, and the other with water. Mix the two portions thoroughly, place in the test tube, add one half inch of water, and the cork. Allow the tube to stand for several days, and observe the differentiation of the included air, oil, and water. In the

sand at the top of the tube there will be air, below it oil saturated sand, and water at the bottom. Colour the water with red or blue ink to make the results more evident.

4. Make a model of an oil-bearing anticline using clay and sand. Figure 100 may be used as a pattern. Section the anticline, and place this surface against glass to prevent drying and cracking.

5. Investigate the possibilities for oil and gas in your district. Are there any surface indications? Are the strata dipping or flat-lying? What is the structure of the strata? Has there been a wildcat drilled in your district or close to it? Were any promising results obtained? What were they? At what depths and in what formations were shows of oil and gas obtained? Make a diagram of the well log to show the formations encountered and their relative thicknesses. Examine a spring, slough or other body of stagnant water in order to find an irridescent film on the surface. Is this film oil or iron hydrate? Put a drop of oil on the surface of water, and then touch the film of oil to observe its behaviour.

6. Make a large drawing of the Turner Valley anticline. Obtain from the Department of Lands and Mines, Petroleum and Natural Gas Division, Calgary, a type well-log of the Turner Valley field. This gives the names and average thicknesses of the formations encountered in drilling in this field. Colour each formation differently to make the log more easily read.

Gold:

Get a shovelful of sand from a local stream and pan it for gold. Put the sand in a dishpan, wash basin, or frying pan; then mix thoroughly with water. Remove any large pebbles. Hold the pan in both hands, and swirl the contents round and round by rocking the pan gently with a rotary motion. Allow some of the mud and sand to escape over the side from time to time, and add more water as it is needed. Continue this proceeding until only a small residue is left in the bottom; examine it carefully for flakes of gold, which will be readily seen if they are present. The high specific gravity of gold is used to separate it from the other minerals which make up sand; stirring the mixture in water enables the heavy minerals to settle to the bottom, so that care is necessary in pouring off sand and mud in order to retain the gold. Magnetite (black sand) and garnet will be the principle minerals found in the residue. Many trials are necessary to acquire the technique involved; therefore one should not be discouraged after one negative trial.

Bentonite:

It is possible that you may find a seam of this mineral in your district in the Benton, Belly River, Edmonton, and Paskapoo formations, for these strata contain considerable bentonite. A seam can be detected as a light cream or greenish band in the darker coloured rock. When the mineral is wetted with water, it has a greasy feel and swells to several times its original size.

Bituminous Sands:

Place a small piece of bituminous sandstone from McMurray in gasoline or ether, and allow to stand for a few hours. Shake occasionally, and the sandstone disintegrates, for the bitumen, which is the cement, is dissolved. Pour the liquid into an evaporating dish, let the solvent evaporate and note the tarry residue. Then take the sand, wash it in more gasoline, and examine the sand grains with a magnifying glass. It will be seen that the grains are pure, white quartz.

Building Stones:

Note any stone buildings or any structures trimmed with stone. Make inquiries to learn the name and source of the stone; also find out the formation from which the stone was obtained. In this way one soon learns to recognize the building stones that are commonly used in Alberta.

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